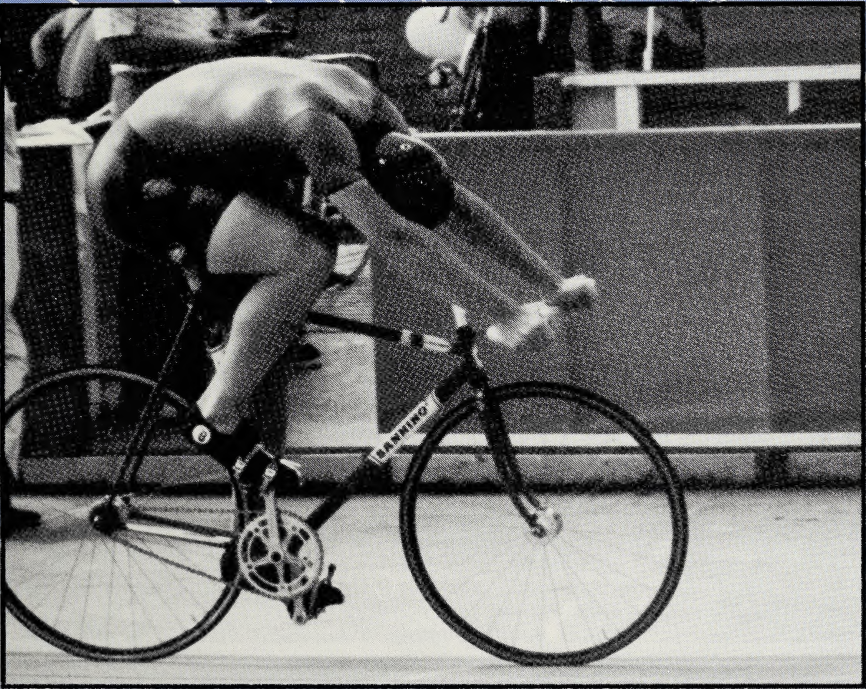
University of Alberta Library
0 1620 3415704 8

PHYSICS 30

2,1994-
16
c.2



Module 1

The Conservation of Energy

Distance Learning

Alberta EDUCATION

CANADIANA
JUL 26 1994

Physics 30

Module 1

The Conservation of Energy

Alberta
EDUCATION

Distance Learning

This document is intended for	
Students	✓
Teachers (Physics 30)	✓
Administrators	
Parents	
General Public	
Other	

Physics 30
Student Module
Module 1
The Conservation of Energy
Alberta Distance Learning Centre
ISBN 0-7741-0924-6

Cover Photo: WESTFILE INC.

ALL RIGHTS RESERVED

Copyright © 1994, the Crown in Right of Alberta, as represented by the Minister of Education, Alberta Education, 11160 Jasper Avenue, Edmonton, Alberta, T5K 0L2. All rights reserved. Additional copies may be obtained from the Learning Resources Distributing Centre.

No part of this courseware may be reproduced in any form, including photocopying (unless otherwise indicated), without the written permission of Alberta Education.

Every effort has been made both to provide proper acknowledgement of the original source and to comply with copyright law. If cases are identified where this has not been done, please notify Alberta Education so appropriate corrective action can be taken.

IT IS STRICTLY PROHIBITED TO COPY ANY PART OF THESE MATERIALS UNDER THE TERMS OF A LICENCE FROM A COLLECTIVE OR A LICENSING BODY.

UNIVERSITY LIBRARY
UNIVERSITY OF ALBERTA

Welcome to Physics 30!

We hope you'll find this course interesting.

To make your learning a bit easier, many different resources will be presented throughout the course. Some of these resources, such as your textbook, videocassettes, and laser videodiscs, will be flagged with the following icons:

MERRILL
P•H•Y•S•I•C•S
PRINCIPLES AND PROBLEMS

Frame 4850A

When you see these icons, follow the instructions in your module booklet and go to the appropriate resource.

One important resource that you'll be using all the time is your notebook.

There are no response lines to write on in many of the questions asked in the Student Module Booklet of this course. This means that you will need to have lined paper handy at all times on which to answer the questions. It's probably a good idea if you keep your answer pages in a notebook or binder so that they do not get lost and they are easier to refer to when reviewing or studying. Read all the questions carefully and answer them as completely as possible. Then check your answers in the Appendix.

It is also important that you work through the module activities thoroughly before attempting the questions in the Assignment Booklet. This will help you to achieve a greater degree of success in your studies.

Good Luck!

Course Overview

This course contains nine modules. The first two modules develop the conservation laws of energy and momentum. The conservation of energy is at the heart of the entire course. Modules 3 through 9 build one upon the other and incorporate the main ideas from the preceding modules.

The module you are working in is highlighted in a darker colour.

PHYSICS 30

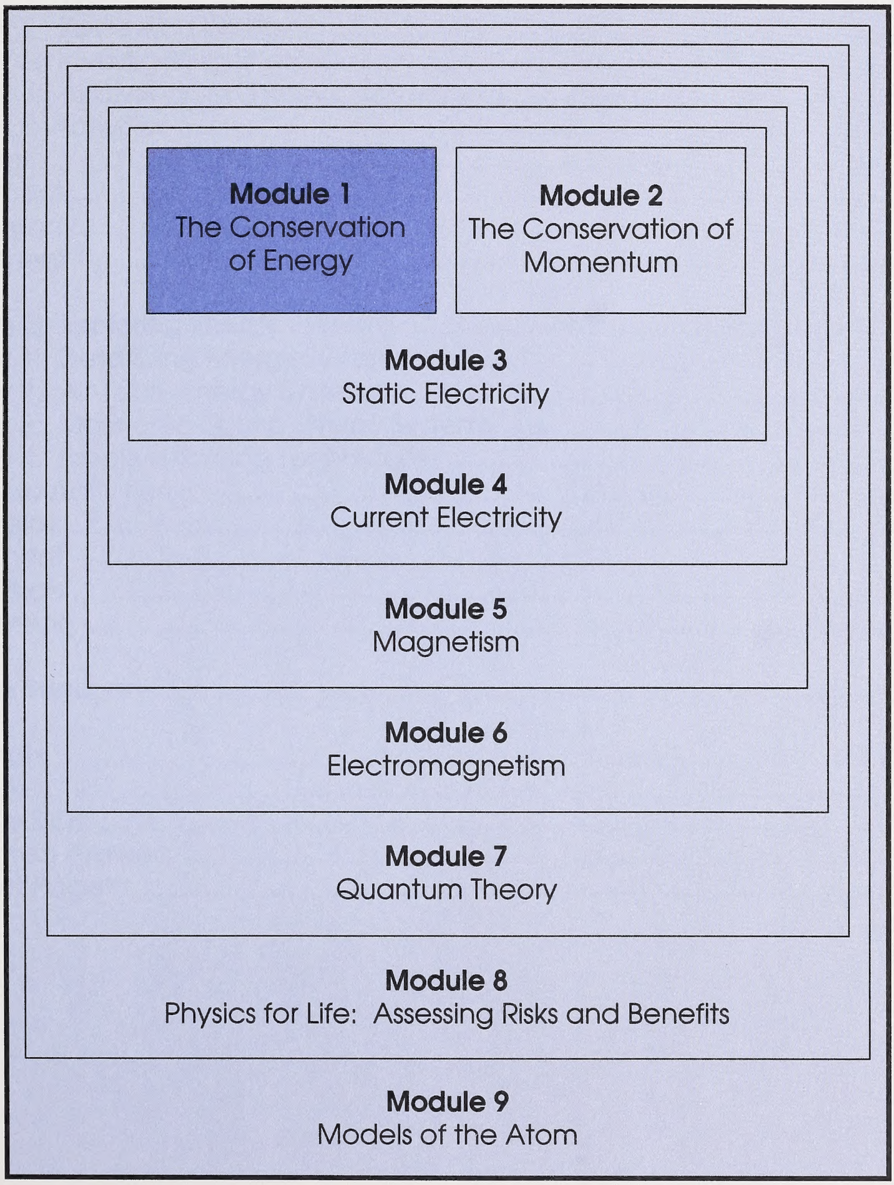


Table of Contents

Overview 1
Evaluation 2
Science Skills 2

Section 1: Starting with Energy and Foresight 5
Activity 1: Working to Success 6
Activity 2: Reviewing Energy 12
Activity 3: Investigating Energy 16
Activity 4: Analysing an Energy Conversion 21
Follow-up Activities 31
Extra Help 31
Enrichment 33
Conclusion 34
Assignment 34

Section 2: Exploring Energy Systems 35
Activity 1: Describing Energy Systems 36
Activity 2: Air-Table Energy Systems 40
Activity 3: Mass-on-a-Spring Energy Systems 47
Activity 4: Problem-Solving Techniques 54
Follow-up Activities 65
Extra Help 65
Enrichment 68
Conclusion 71
Assignment 71

Module Summary 71

Appendix 73
Glossary 74
Science Skills 75
Suggested Answers 81
Tear-out Page 121

Digitized by the Internet Archive
in 2017 with funding from
University of Alberta Libraries

https://archive.org/details/physics3001albe_0

OVERVIEW

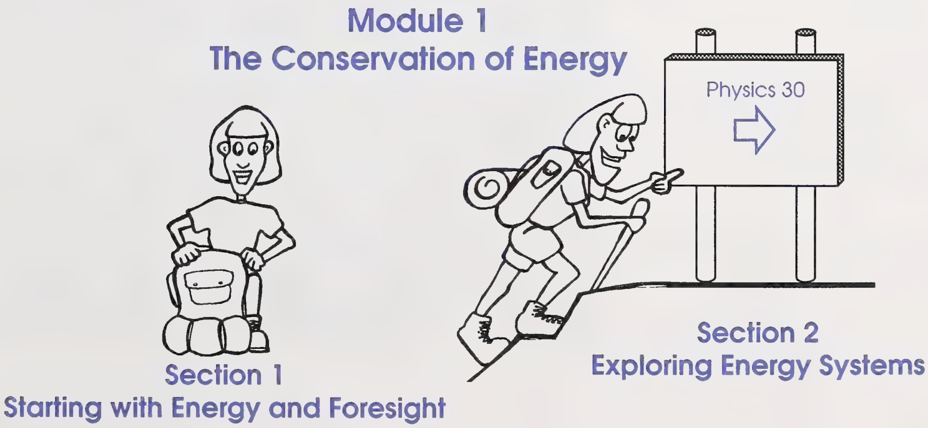
If you could win an all-expenses-paid trip to anywhere in the world, where would you want to go? Would you choose an adventure holiday and explore an exotic place? Perhaps you would prefer an ocean beach with warm water and lots of tropical sun. Close your eyes and imagine yourself on your ultimate holiday. Try to visualize what a typical day would be like, the kinds of things that you would do, and the kinds of things that you would like to take along.

How would you prepare for this trip? Would you need specialty items like foreign currency, special clothes, or sporting equipment? What would you need to pack? You wouldn't want to miss out on all that this experience has to offer, so you might phone around and talk to some people who have done this kind of thing before. You might even try to contact people at the place you're going to get some recommendations about how to prepare yourself to get the most from this holiday. Perhaps you would take some lessons in a foreign language, or you might need to start training to improve your level of fitness. The list of possible preparations is endless.

Even though the all-expenses-paid holiday is just a great daydream, it does make one important point – what you need to take along and how you prepare depends on where you want to go. **The destination determines the type of preparation.**

The same can be said about learning. The nature of the subject that you are learning determines the kinds of skills that you need, as well as how you must prepare before you start.

The first module of Physics 30 is designed to help you prepare for a successful experience in the course. The first section clarifies what you will be learning, how you will need to prepare, and what you can expect to be doing in your daily work. In the second section you will study various energy systems. The orientation that you get in Section 2 will provide an essential guide to the rest of the program.


Module 1
The Conservation of Energy
Physics 30
Section 1
Starting with Energy and Foresight
Section 2
Exploring Energy Systems

Evaluation

Your mark in this module will be determined by your work in the Assignment Booklet. You must complete all assignments. In this module you are expected to complete two section assignments. The mark distribution is as follows:

Section 1 Assignment	40 marks
Section 2 Assignment	60 marks
TOTAL	**100 marks**

Science Skills

One of the exciting features of this course is that you will develop and improve your ability in the area of science skills. These skills include the following:

- initiating and planning
- collecting and recording
- organizing and communicating
- analysing
- connecting, synthesizing, and integrating
- evaluating the process or outcomes

Although these skills are referred to as science skills, it is important to remember two key ideas.

First, these skills are not just for science. Any time that you solve a problem or make a decision, some combination of these skills is used.

PHOTO SEARCH LTD.

Therefore, the skills that you will develop in this course will be very useful for life-long learning. Nearly every activity of your life will require you to solve a problem or make a decision. Some people would even argue that the skills are more important than the particular topics that you study.

Secondly, you will be free to use these skills in a variety of ways. It would be wrong to assume that every scientist uses these skills in the same way to solve every problem. Science is very much a human activity, which means individuality and creativity play a large role.

NASA

NATIONAL RESEARCH COUNCIL CANADA

The society that the person lives in, the technology that is available, and the very personality of the scientist will determine which skills are combined to create a solution to a problem.

The science that you do and the science skills that you prefer to use will be unique to you. Also, you likely will not be performing at the same level for all skills. In this course you will continually practise all of these skills and you will have an opportunity to assess your level of performance in each skill.

These science skills will be developed further in Section 1 and explained in detail in the Appendix.

Section 1

Starting with Energy and Foresight

WESTFILE INC.

Imagine that you are riding this tramcar to the top of a mountain. On the way up you peek over the railing and look down to the rocks, trees, and valley below.

What thoughts would be going through your mind? Most people would be overwhelmed by the scenery. However, if you're the kind of person who doesn't like heights, the view could be both glorious and terrifying at the same time! In these circumstances you might try to reassure yourself with the perfect safety record of the tramcar; after all, you remember reading the brochure that outlined all the energy and safety requirements of the system. The brochure said that the engineers used **foresight** when they designed the tramcar system. This means that they exercised good judgement and common sense.

The ride doesn't seem quite so scary now. The view is breathtaking – both because of the rugged terrain and because of the altitude!

Why is the description of the tramcar an appropriate way to begin Physics 30? One reason is that the concepts of work and energy that are the basis for the tramcar's operation are also the ideas that are at the centre of the course. Another reason why this description is appropriate is that your role as a student in Physics 30 has many similarities to the role of the engineers who designed the tramcar. Both roles require the analysis of energy systems and foresight. In your case, foresight is not required for safety; you need foresight to help keep in mind the big ideas, like energy, while not forgetting about the little details.

In this section you will begin to learn techniques to integrate the need for considering the big ideas with the need for attending to the little details. This will be done in a review of work and energy. You will also apply the skills of science by collecting and recording data in investigations of energy systems. In the final activity you will analyse the data that you collected and evaluate the experimental design.

Activity 1: Working to Success

Have you ever stood in line with a very heavy package? "If only I had thought of getting a cart!" you say to yourself. Meanwhile, you stand there and struggle with your heavy load while you wait your turn.

Do you know that in this situation you are doing no work on the object you are carrying? This might not seem right until you consider the definition of **work** in physics.

work – the product of force and displacement

Work = Force × Displacement

- Work is done **on** something.
- Work is done **against some resistance.**

- The displacement must be in the **same direction** as the force.

Since your heavy load didn't move, no work was done on it.

joule – the SI unit of work and energy; the work done when a 1-N force is exerted over a 1-m displacement

The SI unit for work is the **joule** (J). From the definition of work, the meaning of a joule can be illustrated as follows:

Work = Force × Displacement

Substitute units for each quantity.

joule = newton • metre

Substitute symbols for each unit.

J = N • m

I remember that! That's a really easy equation!
A joule is certainly a small unit isn't it? Lifting a small apple through 1 m is about 1 J of work.

power – the rate of doing work or the rate of using energy

The rate of doing work seems to be important too. If you quickly lift several boxes into a truck, you get more tired than if you do the same work slowly. This rate is called **power**.

watt – the SI unit of power; equal to 1 J of work per second

The SI unit for power is the **watt**, which is equal to 1 J/s.

Following is a sample problem. Note the strategies for successful problem solving that are written beside the solution.

Example

Jack pushes on a 10.4-kg box. He exerts a 100-N force and pushes it 10.62 m across the floor in 6.8 s. Calculate the work done on the box and the power output by Jack.

Solution

Problem-Solving Strategies

$$\begin{aligned} m &= 10.4\ \text{kg} \\ F &= 100\ \text{N} \\ d &= 10.62\ \text{m} \\ t &= 6.8\ \text{s} \\ W &= ? \\ P &= ? \end{aligned}$$

Read carefully! More than half of the mistakes made when solving problems are reading mistakes!

What has been given? What must you find? Record these things concisely at the beginning. Do you need **all** the data?

$$\begin{aligned} \text{Step 1: } W &= Fd \\ &= (100\ \text{N})(10.62\ \text{m}) \\ &= 1062\ \text{J} \\ &= 1.06 \times 10^{3}\ \text{J} \end{aligned}$$

Always start with the equation, rearrange if necessary, substitute in the data, and then solve.

Always round the answer to the correct number of significant digits. In Physics 30 100 N is considered to have three significant digits, so your answer should be rounded to three digits too.

$$\text{Step 2: } P = \frac{W}{t}$$

$$= \frac{1062\ \text{J}}{6.8\ \text{s}}$$

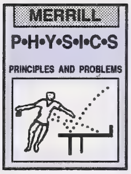
$$= 156.176\,47\ldots\ \text{W}$$

$$= 1.6 \times 10^{2}\ \text{W}$$

If you must use an already calculated value, always use the **unrounded** value.

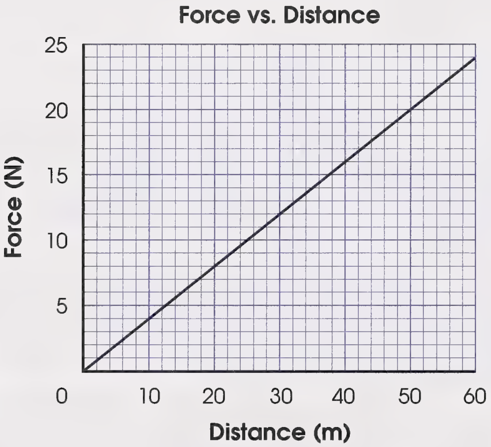
Round to the correct number of significant digits at the **end** of the problem.

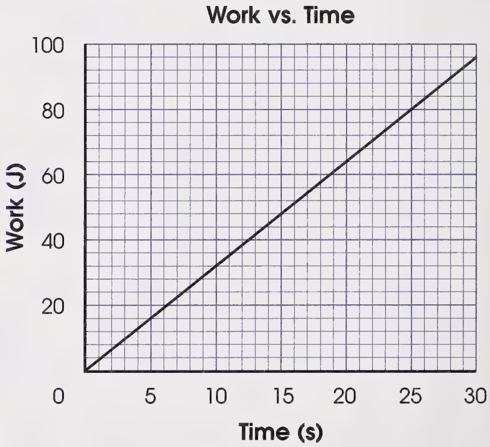
1. Why does your arm get so tired when you hold a book if no work is done? Where is the work done?



2. Do Chapter 10 questions 2, 3, and 10 on pages 695 and 696 of your textbook.
3. Do Chapter 10 questions 7 and 8 on page 696 of your textbook. Remember that the force and distance must be in the same direction. You may need to use trigonometry.
4. Do Chapter 10 questions 1, 9, and 12 on pages 695 and 696 of your textbook.

A graph can also help you calculate work and power. Work is the area under a force-distance graph. Since power is a rate, and a slope shows a rate, power is the slope of a work-time graph.





The work done over 50 m is calculated as shown.

$$\text{area} = \frac{1}{2}ab$$

$$= \frac{1}{2}(20\ \text{N})(50\ \text{m})$$

$$= 5.0 \times 10^{2}\ \text{J}$$

The power of this device is calculated as shown.

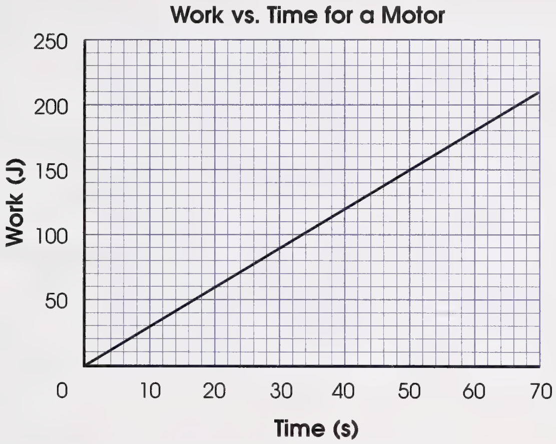
$$\text{slope} = \frac{\text{rise}}{\text{run}}$$

$$= \frac{80\ \text{J}}{25\ \text{s}}$$

$$= 3.2\ \text{W}$$

5. Do Problem 5, which is near the bottom of page 213, and Problem 20 on page 214 in your textbook.

6. Find the power output of the motor that produced this graph.



Check your answers by turning to the Appendix, Section 1: Activity 1.

You likely noticed that the previous questions relied heavily on the physics that you learned in Physics 20.

If you find that you need to refresh your memory with more detailed explanations, turn to the appropriate section of your textbook and review the main ideas. You will want to make sure that you understand what you read, so you should probably study the Example Problems and do some of the relevant Practice Problems too. You can find more information about work and energy on pages 196 to 203 of your textbook and you can check your understanding by doing some of the Practice Problems on those pages. The textbook has the answers to all the Practice Problems for each chapter on pages 656 to 687.

You may find that you have to return to the textbook and give yourself some more practice periodically throughout the course. The main thing to remember is that you learn physics by doing problems, not by reading only, so always keep your calculator and notebook handy.

7. If you need more explanation of the topic of kinetic energy, what pages should you refer to in your textbook?

8. How would you check to see if you understood what you just read about the topic of kinetic energy?

Although you will need to learn many things to be successful in Physics 30, one thing that you won't have to do is memorize all the equations. Since the goal is to **understand** the main concepts and to see how these concepts **apply** to other ideas in the fields of science, technology, and society, it is not crucial for you to memorize the equations or the physics constants. All the equations that you will need can be found in the Physics 30 data sheets. This is the one reference that you can use when you write your Physics 30 diploma exam at the end of the course.

The Physics 30 data sheets can be found at the end of the Appendix in Module 9.

It's a good idea to use these sheets when you are answering activity questions and doing assignments so that you can learn the location of all the equations and constants, and so that you can become comfortable with using them. The other advantage of using the data sheets on a regular basis is that they will help you to form habits that will make you more successful when you write your diploma exam. The following questions illustrate how helpful the data sheets can be.

9. Find the equations for work and power in the Physics 30 data sheets. How do these equations compare to the ones used in the Appendix of this module?
10. Find the value for the acceleration due to gravity in the Physics 30 data sheets. How does this value compare to the one used in the Appendix of this module and to the value used in the Example Problem on page 224 of your textbook?

Check your answers by turning to the Appendix, Section 1: Activity 1.

The answers to the previous questions indicate some important relationships between your work in the Physics 30 modules and the diploma exam.

The diploma exam attempts to evaluate the things you learn in Physics 30 that can be tested by a pencil-and-paper exam. While doing the exam, you are expected to use the equations and constants which appear in the Physics 30 data sheets. For example, you are expected to use **$9.81\ \mathrm{m/s^2}$**, which is the average Alberta value for the acceleration due to gravity, **not** $9.80\ \mathrm{m/s^2}$, which is the value used in the textbook.

The section assignments will give you practice with the kinds of questions that will be asked on the diploma exam. You should use the versions of the equations and constants from the data sheets when you do the section assignments. This is one example of how the assignments are aligned with the diploma exam.

The questions in the activities and the corresponding answers in the Appendix of each module will help to prepare you for the section assignments. **It is vital that you check your work by carefully comparing your answers to the samples presented in the Appendix of each module.** The answers in the Appendix have been developed to reflect the Physics 30 data sheets and the method of solution that is expected on the diploma exam. This is one way that the Appendix answers are aligned with the section assignments and the diploma exam.

Finally, the activities in the module booklets will provide examples and the kinds of coaching that you will need to help you be successful on the diploma exam. For example, the problem-solving strategies shown earlier in this activity are the same ones that you should use when you answer a written-response question on the diploma exam. If you don't follow this format, you could lose marks on the exam because you didn't communicate your answers properly. By practising the proper techniques on activities and assignments, you'll develop the kind of habits that you'll need for the diploma exam.

So you can see that the examples, activity questions, Appendix answers, and assignment questions are all aligned with the diploma exam to give you a consistent approach that is designed to help you be successful.

11. Suppose a student decided to ignore the suggestions in the module activities and to answer questions by just plugging numbers into a calculator. "After all," this student might say, "I get the same answer. Why write all that stuff down?" Explain why this strategy is not a good idea.

12. The student described in the previous question was overheard making this comment while doing the first assignment in Physics 30: "I could get all the answers when I plugged numbers into my calculator while looking at the Appendix, but I can't figure anything out now!" Suggest the reason for this student's frustration.

13. A student was asked to calculate the work required to lift a 9.0-kg bag of fertilizer through a distance of 6.97 m. Unfortunately, the student did the calculation as shown. Redo this calculation properly by using the guidelines given in this activity. Write out each step of your calculation to show the correct problem-solving strategies.

$$\begin{array}{r} 9.0 \\ \times\ 9.8 \\ \hline 88.2 \end{array} \qquad \begin{aligned} \text{work} &= 88.2 \times 6.97 \\ &= 614.754\ \text{N} \\ &= 6.1 \times 10^{2}\ \text{N} \end{aligned}$$

This calculation is **not** done properly.

14. Outline the approach that you will use as you work through the activities and assignments in the Physics 30 modules.

Check your answers by turning to the Appendix, Section 1: Activity 1.

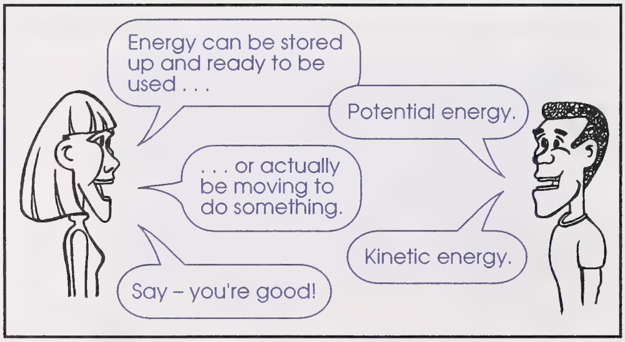
One definition of success that athletes use is the idea of personal best. A cross-country runner may be attempting to win a race, just like all the other runners, but a more workable goal would be to finish the race with a time that is the personal best time for that individual runner. If this time is good enough to win, even better, but the goal of attaining personal best gives the runner a sense that he or she owns the race, and that he or she also owns the outcome.

In a similar way, you could commit to doing your personal best in Physics 30. You could decide that you own the course and that you will also own the outcome. The problems in the textbook, activities, and assignments are the equivalent of a runner's training. Just as a runner can't achieve a peak performance without proper conditioning, the same can be said about your performance in Physics 30. If you decide to do your best, and take full advantage of the coaching and training in the activities of each module, you should be able to learn a lot of physics and experience success in the course.

Activity 2: Reviewing Energy

Have you ever taken a ride in an old steam-powered train? A steam engine works on the principles of heat **energy**, but these principles were really hard to work out. In Isaac Newton's time, heat was considered to be a fluid, not a form of energy. Today's definition relates energy to work done. These two concepts are closely related. In fact they share the same unit, the joule.

energy – the ability to do work or cause a disturbance in a system's surroundings

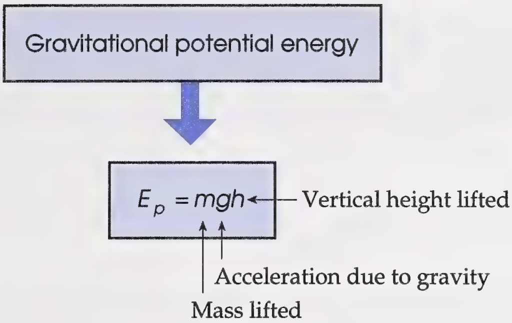

Energy can be stored up and ready to be used . . .
Potential energy.
. . . or actually be moving to do something.
Kinetic energy.
Say – you're good!

My name's Nicole. Glad to meet you.
I'm Mike.

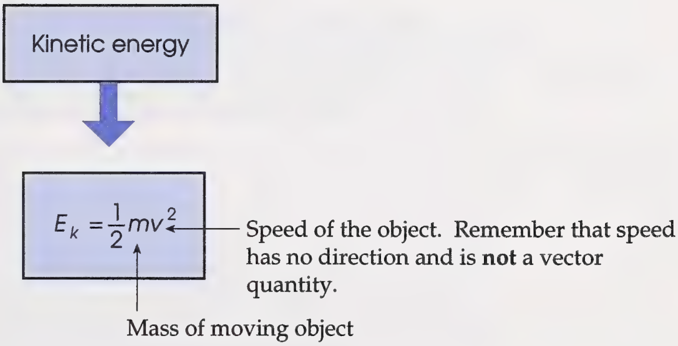
Energy has many forms: gravitational potential, chemical potential, and kinetic.

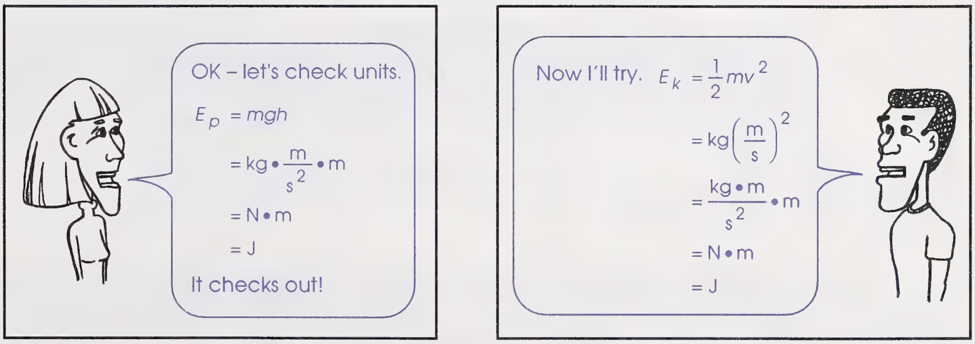
Each form has a mathematical formula to express the energy value, but the units **always** simplify to joules.

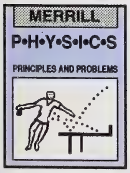
gravitational potential energy – the work done against gravity to change the position of an object



kinetic energy – energy due to the motion of an object


Kinetic energy
$E_k = \frac{1}{2}mv^2$
Speed of the object. Remember that speed has no direction and is **not** a vector quantity.
Mass of moving object


OK – let's check units.
$E_p = mgh$
$= \text{kg} \bullet \frac{\text{m}}{\text{s}^2} \bullet \text{m}$
$= \text{N} \bullet \text{m}$
$= \text{J}$
It checks out!
Now I'll try. $E_k = \frac{1}{2}mv^2$
$= \text{kg}\left(\frac{\text{m}}{\text{s}}\right)^2$
$= \frac{\text{kg} \bullet \text{m}}{\text{s}^2} \bullet \text{m}$
$= \text{N} \bullet \text{m}$
$= \text{J}$



To review the key ideas about kinetic energy, carefully read pages 218 to 221 in your textbook. Study the Example Problem on page 221 and then answer the following questions.

1. Do Practice Problems 3 and 4 on page 222 of your textbook.

Read pages 222 to 224 of your textbook to review the key ideas about potential energy. Study the Example Problem on page 224 and then answer the following questions.

2. Do Practice Problems 5 and 6 on page 224 of your textbook.

Check your answers by turning to pages 672 and 673 of your textbook.

One of the most important things that you should have noticed about potential energy is the idea of a **reference level**.

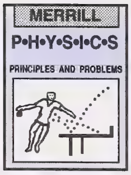
3. What is the reference level and why is it important that it does not change in the middle of a problem?

Check your answers by turning to the Appendix, Section 1: Activity 2.

There are two main ideas that you learned about energy in Physics 20:

The amount of energy an object has is equal to the work done on that object to put it in the state it's in.

An isolated system has a constant **total** energy. One kind of energy can change to another but the total remains the same.



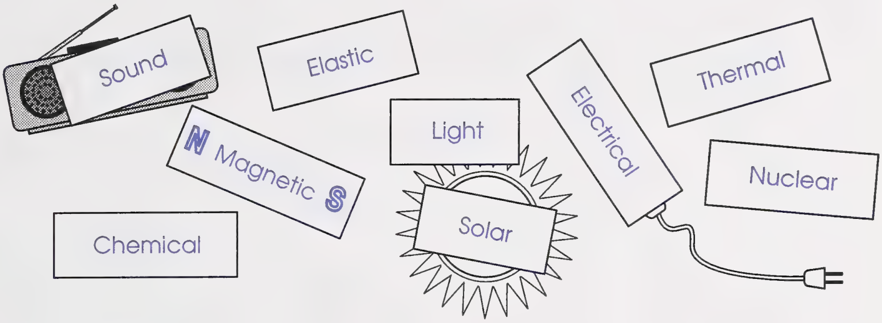
4. Keeping the first idea in mind, try doing Chapter 11 questions 3 and 7 on page 696 of your textbook.

5. Keeping the second idea in mind, try doing Chapter 11 questions 9 and 11 on page 696 of your textbook.

Check your answers by turning to the Appendix, Section 1: Activity 2.

mechanical energy – the sum of kinetic and potential energy

The two forms of energy used in the previous problems are called **mechanical energy**. There are lots of other types. Some are listed here for you.



No matter what kind of energy you analyse, the equation will give an answer for energy in joules. So, all kinds of energy are interchangeable. You will see this later in the course when you study electricity and quantum theory.

Solve the following problems. Keep in mind that one form of energy can transform into another. Assume that frictional effects can be ignored.

6. An electric motor is rated at 25 W of power. How high can it lift a 2.0-kg block in 30 s?

7. A 70.0-kg person jumps on a trampoline and does 1.40 kJ of work on it while stretching it downward. How high should he be able to jump?

8. An average force of 100 N is exerted on a bow as it is pulled back 75.0 cm to release a 150-g arrow.

    a. What speed will the arrow have when it is released?

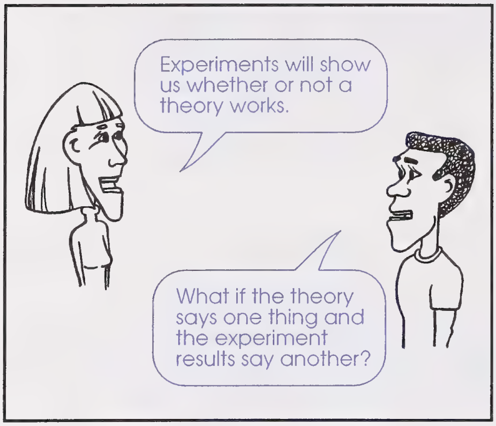
    b. How high should it be able to go if it is shot straight up into the air?

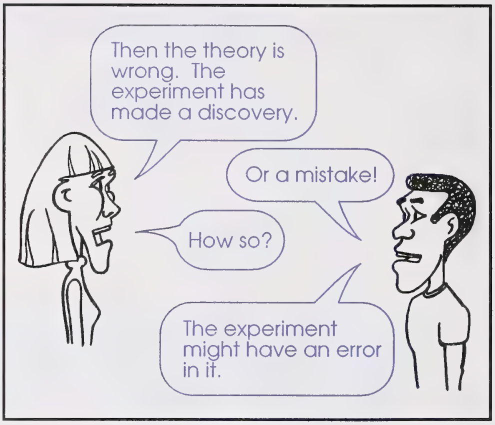
9. A skier races down a hill with an elevation drop of 1100 m. What speed should the skier have at the bottom? (Hint: Derive an expression for the final speed before substituting values.)

Check your answers by turning to the Appendix, Section 1: Activity 2.

Activity 3: Investigating Energy

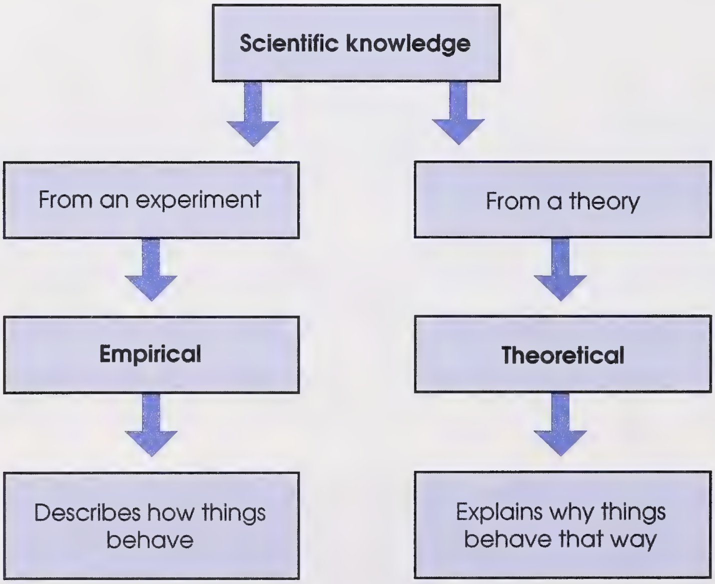
All the theory you learn in any science course exists to explain why things behave as they do. An experiment is the process that lets scientists determine if a particular theory works or not.


Experiments will show us whether or not a theory works.
What if the theory says one thing and the experiment results say another?

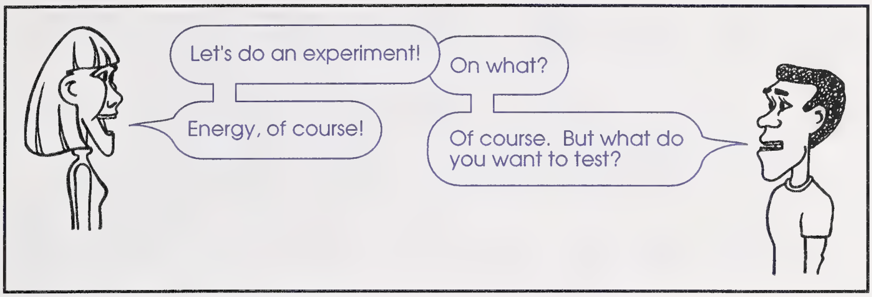

Then the theory is wrong. The experiment has made a discovery.
Or a mistake!
How so?
The experiment might have an error in it.

empirical knowledge – knowledge gained from experiencing something; describes events

theoretical knowledge – knowledge gained by developing theories, models and other constructs; explains why



The empirical side is the deciding one. Theories must correctly predict experimental results.


Let's do an experiment!
On what?
Energy, of course!
Of course. But what do you want to test?

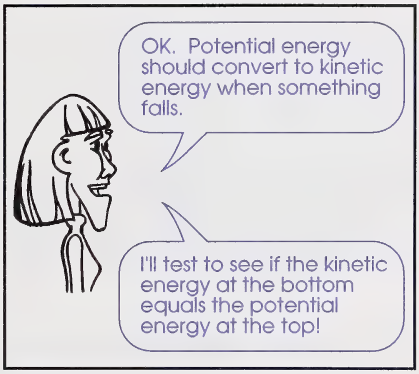
problem – the specific question that an experiment is to answer

prediction – a guess about how an experiment will turn out

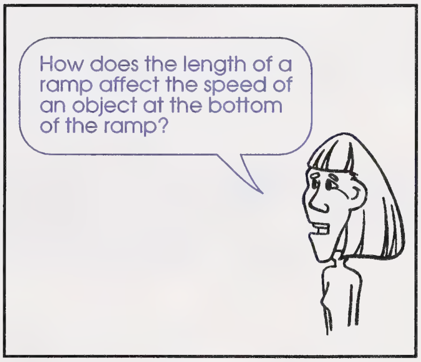
hypothesis – theoretical knowledge on which a prediction is based

In order to design an experiment, start with a **problem** you want to test. State the problem in a way that lets you run an experiment to solve it. You then predict the outcome of your experiment, based on what you know about the subject. This theoretical knowledge you base your **prediction** on is a working **hypothesis**. Finally, design an experiment that can answer your problem and either verify or falsify your prediction. The design stage includes listing the materials and the controlled and manipulated variables, and outlining the step-by-step procedure. The following cartoons illustrate how Nicole designed an experiment to explore energy conversion.

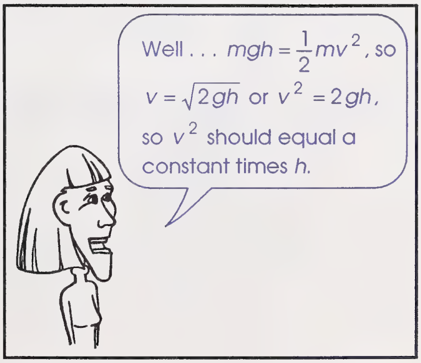
Step 1: Search for a working hypothesis to test.


OK. Potential energy should convert to kinetic energy when something falls.
I'll test to see if the kinetic energy at the bottom equals the potential energy at the top!

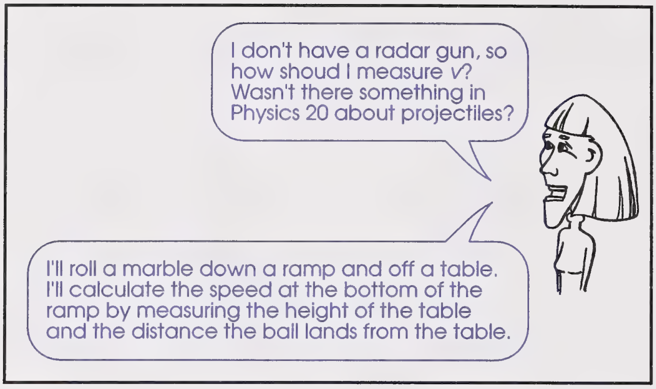
Step 2: State a problem in a way that makes it testable.


How does the length of a ramp affect the speed of an object at the bottom of the ramp?

Step 3: Predict the outcome based on your working hypothesis.


Well . . . $mgh = \frac{1}{2}mv^2$, so $v = \sqrt{2gh}$ or $v^2 = 2gh$, so v^2 should equal a constant times h.

Step 4: Think about technical problems and develop an overview of how you should proceed. This will be the basis of your detailed design.


I don't have a radar gun, so how shoud I measure v? Wasn't there something in Physics 20 about projectiles?
I'll roll a marble down a ramp and off a table. I'll calculate the speed at the bottom of the ramp by measuring the height of the table and the distance the ball lands from the table.

science skills – problem-solving skills useful in science and in daily life

This whole process of progressing from a problem through to a hypothesis and then to an experimental design comes under the category of initiating and planning. This is one of the six categories of **science skills** that you'll be practising as a part of this course. The science skills usually progress in the following order:

- initiating and planning
- collecting and recording
- organizing and communicating
- analysing
- connecting, synthesizing, and integrating
- evaluating the process or outcomes

Science Skills

☑ A. Initiating
☐ B. Collecting
☐ C. Organizing
☐ D. Analysing
☐ E. Synthesizing
☐ F. Evaluating

When you practise using one of the skills in each category, you'll be shown an icon like the one in the margin. Note that the names of the categories have been shortened to just one word and that only the categories being practised will have a check mark beside them.

A detailed description of each skill can be found at the beginning of the Appendix. Turn to the Appendix and read A Framework for Scientific Problem-Solving Skills to familiarize yourself with what each skill means.

1. The following series of events illustrates how the science skills can be applied to the solution of an everyday problem. Use the description of the science skills in the Appendix to decide which of the six skills best matches each part of the story. You may have to use some of the science skills more than once.

   a. Ahmed has decided to buy a portable cassette player. "How can I purchase a quality machine with the features that I want and still stay within my budget?" he asks himself.

b. First he decides which features are important and which brand names seem to have a reputation for quality.

c. Ahmed devises a plan to find the best deal.

d. Ahmed begins to visit stores to listen to different machines and compare features.

e. Ahmed takes notes at each store so he doesn't forget all the details.

f. Ahmed summarizes his notes by putting all the information in one chart. He shows this chart to some friends to get their insights and opinions.

g. Ahmed sits down and carefully examines all his data. He tries to identify the main attributes of the machine that will best fit his needs. Unfortunately, the machine he wants doesn't fit within his budget.

h. Ahmed tries to identify alternatives. How can he get the machine he wants and not overspend?

i. Ahmed hears about a friend who wants to sell the exact model he is looking for second-hand. The machine seems to be in good condition and is only six months old. Ahmed decides to buy this machine.

j. Ahmed sits back and listens to his new cassette player. He decides that it was a good idea to shop around and be patient because his new machine sounds great and he was able to stay within his budget.

Check your answers by turning to the Appendix, Section 1: Activity 3.

In the next investigation you will have a chance to practise the skills of collecting and organizing information as you carry out the procedure that Nicole designed.

Investigation: Projectile Marbles

Science Skills

☐ A. Initiating
☑ B. Collecting
☑ C. Organizing
☐ D. Analysing
☐ E. Synthesizing
☐ F. Evaluating

Purpose

In this investigation you will roll a marble off the edge of a table to determine how the height of a ramp relates to the horizontal distance travelled by a projectile marble.

Materials

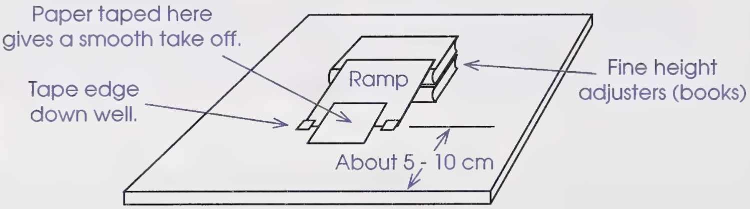
- ramp of some kind (cardboard, wood, glass, etc.)
- masking tape
- paper
- two marbles
- metre stick or measuring tape

Procedure and Observations

- Read the entire Procedure and Observations section **before** you begin. You will be asked to write your observations into a data chart as you do the procedure. A completed data chart will be included in the Appendix for your reference.
- Copy a chart with these headings into your notebook. Be careful to leave enough space under each heading to record your answers. A completed data chart will be included in the Appendix for your reference.

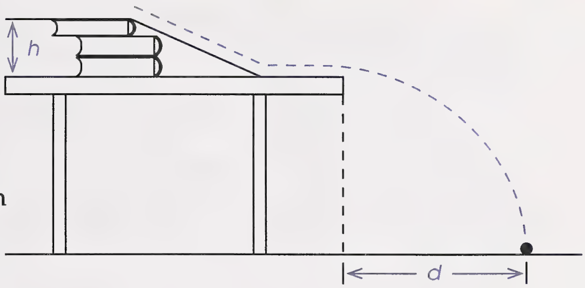
Trial	**Ramp Height (*h*) (m)**	**Horizontal Distance Travelled (*d*) (m)**

- Set up the ramp on a table as shown in the following diagram. The books are used to raise and lower the ramp.


Paper taped here gives a smooth take off.
Tape edge down well.
Ramp
Fine height adjusters (books)
About 5 - 10 cm

- Measure and record the height of the tabletop from the floor.
- Put a mark on the floor directly below the edge of the table. A weight on a thread will help you do this.
- Adjust the books so the ramp is 6.0 cm high. Record the ramp height (*h*) in your data chart.

- Release the marble from the top of the ramp and mark where it lands. Repeat this step until you're sure you've got the correct spot marked. (Hint: Use other marbles to mark each landing spot. When you hit these markers, you'll know you're getting it right.)



- Measure and record the horizontal distance (*d*) on your data chart.
- Raise the ramp 2.0 cm at a time and repeat the previous steps. Record the ramp height (*h*) and the horizontal distance (*d*) for each trial on your data chart. Repeat this process until the ramp is 16.0 cm high.

Conclusion

2. How does increasing the height of the ramp influence the horizontal distance travelled by the marble?

Check your answers by turning to the Appendix, Section 1: Activity 3.

analysis – the identifying of trends, patterns, relationships, and accuracy in an experiment

Now that you have collected the data, the next step will be to closely examine your measurements and complete an analysis to solve the problem proposed by Nicole.

synthesizing – putting ideas together; constructing a whole from the parts

Activity 4: Analysing an Energy Conversion

evaluating – determining the significance or worth of an experiment; identifying the limitations of the data

Now that you have done Nicole's experiment, it's time to make sense out of your observations. In physics this often means using your math skills to figure out things that weren't measured directly and to show the nature of the relationships that you're looking for. This analysis will allow you to identify all kinds of patterns. You'll then pull together ideas from physics, math, and other courses and experiences to answer the problem and perhaps see discrepancies in the results. This is the synthesizing part of the experiment. Finally, you'll be evaluating the design by calculating and identifying experimental errors. You will decide whether or not the prediction has held up and suggest improvements to the design.

You will practise the skills of analysing, synthesizing, and evaluating as you return to the data that you collected in the previous investigation.

- The first thing you should do is to prepare a data chart to keep track of your calculations. Copy a chart with the following headings into your notebook. Be careful to leave enough space under each heading to record your answers. Call this Table 1. A completed data chart will be included in the Appendix for your reference.

Table 1

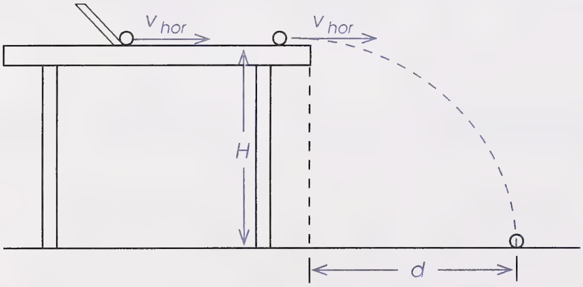
Trial	Ramp Height (*h*) (m)	Horizontal Distance (*d*) (m)	Horizontal Speed (*v*) (m/s)

- Find the values for ramp height and horizontal distance for each trial by referring to the data from the previous investigation. Record these values under the appropriate headings on the data chart.

Science Skills

☐ A. Initiating
☐ B. Collecting
☐ C. Organizing
☑ D. Analysing
☐ E. Synthesizing
☐ F. Evaluating

- Find the horizontal speed of the marble at the bottom of the ramp for each trial. Record your values under the appropriate heading on the data chart. The following hints will help you with the calculations. If friction is ignored, the horizontal speed at the bottom of the ramp is the same as the horizontal speed of the marble as it follows a projectile path to the floor. The following diagram illustrates the main ideas behind this projectile motion.



Horizontal motion is uniform motion, so the following equation applies.

$$\boxed{v_{hor} = \frac{d}{t}}$$

The vertical motion is uniform acceleration with $v_i = 0$ m/s.

$$\boxed{d = v_i t + \frac{1}{2}at^2}$$

$$\Big\downarrow$$

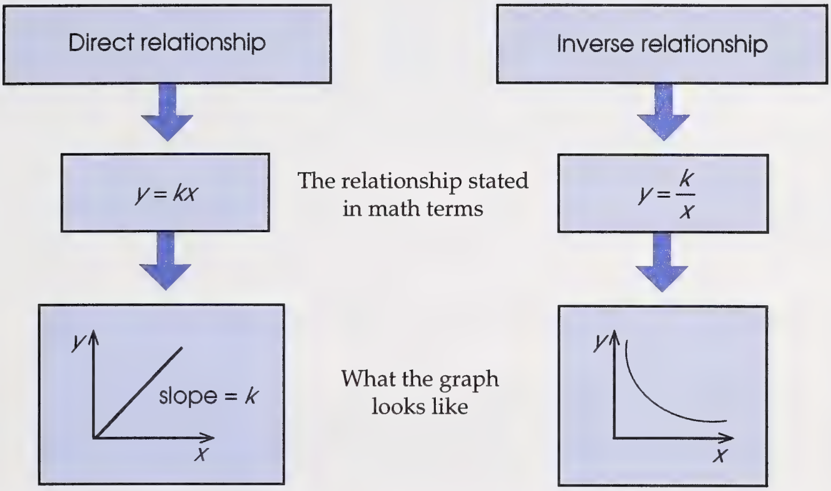
$$\boxed{H = (0)t + \frac{1}{2}gt^2}$$

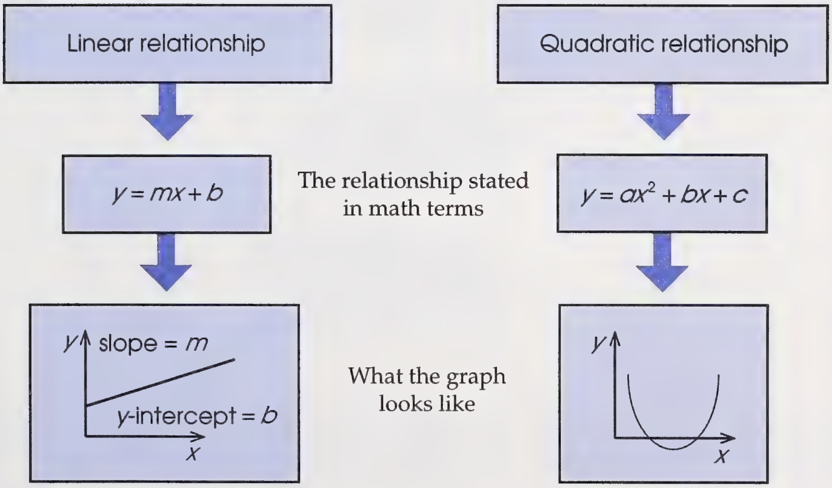
$$\Big\downarrow$$

$$\boxed{H = \frac{1}{2}gt^2}$$

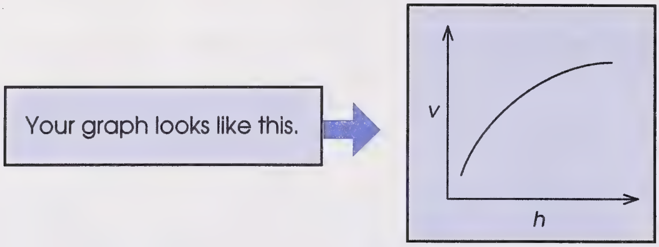
1. Graph the height of the ramp versus the speed at the bottom. Put the manipulated variable on the horizontal axis. Use the standard graph paper with 1-cm squares. Be sure to leave at least nine squares on the horizontal axis and eight squares on the vertical axis.

The graph that you drew in question 1 should have been a curved line. Since curved lines are difficult to analyse, you need to straighten the line. Curve straightening is based on the ideas of variance studied in math courses. The ability to cross over from math to physics is essential here.





Lots of other mathematical relationships exist as well. The trick is to guess which mathematical relationship you have in your graph. A straight line is easiest to analyse, so if you don't have one, make one by graphing other versions of your data.



To get a straight line graph, you will have to manipulate and replot your data. This process begins by returning to the basic physics that was stated in the hypothesis.

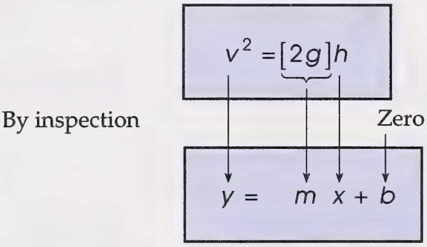
$$E_p = E_k$$

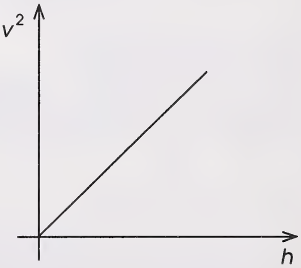
$$mgh = \frac{1}{2}mv^2$$

$$v^2 = 2gh$$

The last equation helps to show why your plot of v versus h gave a curve. Your graph did not include the effects of the exponent, which is an essential part of this relationship. In other words, the fact that the equation says that it is the **square** of the speed that relates to the height means that you should include this in your graph.

By carefully comparing the basic physics equation to the general equation for a linear relationship, you can discover how to replot the data.





If v^2 is the y-variable and h is the x-variable, you should get a straight line through the origin with a slope equal to $2g$.

- To see how this analysis applies to the data, prepare a data chart to keep track of your calculations. Copy the following headings into your notebook. Be careful to leave enough space under each heading to record your answers. Call this Table 2. A completed data chart will be included in the Appendix for your reference.

Table 2

Trial	Ramp Height (*h*) (m)	Horizontal Speed (*v*) (m/s)	Horizontal Speed Squared (v^2) (m^2/s^2)

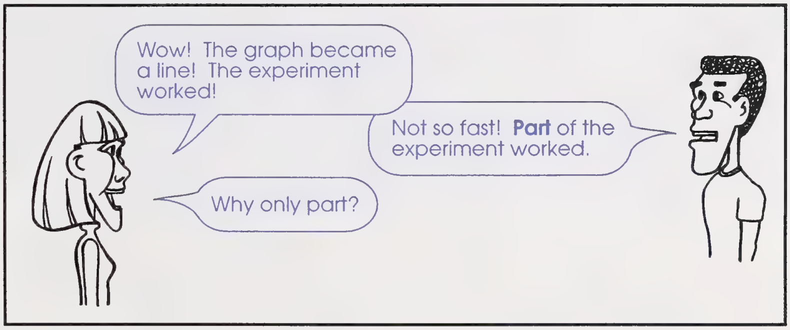
- Find the values for ramp height and horizontal speed for each trial by referring to the earlier calculations. Record these values under the appropriate headings on the data chart.

- Calculate the values of speed squared from the speed values. Record these values on the data chart.

Science Skills

☐ A. Initiating
☐ B. Collecting
☐ C. Organizing
☑ D. Analysing
☑ E. Synthesizing
☐ F. Evaluating

2. Graph the speed squared versus the height of the ramp. Put the manipulated value on the horizontal axis. Use the standard graph paper with 1-cm squares. Be sure to leave at least nine squares on the horizontal axis and ten squares on the vertical axis.


Wow! The graph became a line! The experiment worked!
Not so fast! **Part** of the experiment worked.
Why only part?

3. Calculate the slope of the line. Be sure to include units in this calculation.

A constant slope means a constant something in the experiment.

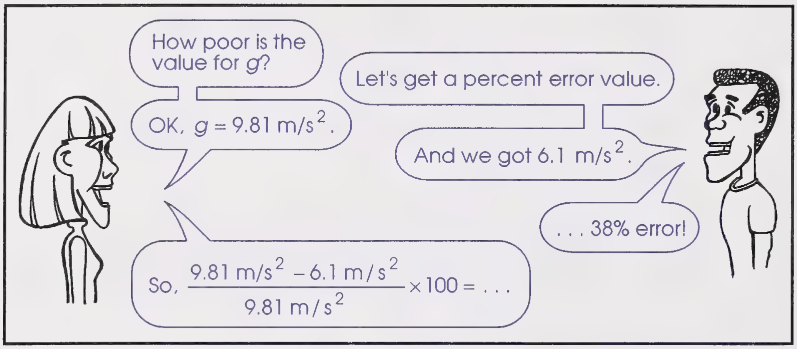
Since $v^2 = 2gh$, the slope should be $2g$.

4. Set the slope equal to $2g$ (notice that the unit of the slope is an acceleration unit) and calculate a value for g from your data.

Check your answers by turning to the Appendix, Section 1: Activity 4.

If your data is similar to the sample results, you will have discovered the following relationships:

- The relationship between height and speed squared is a linear one.
- The relationship is **not** direct since the graph doesn't go through the origin.
- The slope value gives a poor result for g.


How poor is the value for g?
Let's get a percent error value.
OK, $g = 9.81\ \text{m/s}^2$.
And we got $6.1\ \text{m/s}^2$.
. . . 38% error!
So, $\frac{9.81\ \text{m/s}^2 - 6.1\ \text{m/s}^2}{9.81\ \text{m/s}^2} \times 100 = \ldots$

For the crude equipment that was used in this experiment, a 10% to 15% error would be acceptable. The 38% error clearly shows that something else is operating in this experiment. Evaluate the design by answering the following questions.

Science Skills

☐ A. Initiating
☐ B. Collecting
☐ C. Organizing
☐ D. Analysing
☑ E. Synthesizing
☑ F. Evaluating

5. Did Nicole's prediction hold up? Can you verify or falsify it?

6. Was the experimental design adequate to answer the question in the problem?

7. What might the sources of error be?

8. How might the design be improved to get a better result?

Check your answers by turning to the Appendix, Section 1: Activity 4.

The previous investigation and the detailed analysis that followed gave you an opportunity to incorporate many of the key ideas about work and energy from Physics 20. You also had a chance to integrate the main ideas of graphing mathematical relationships as you evaluated the design of the experiment. These tasks are challenging, so you'll be given other opportunities to practise them throughout the course.

The other thing that the previous investigation permitted was an introduction to science skills. It is worth considering how you will be assessed in your ability to use these skills as you encounter them during the course.

As you complete this course you will be continually practising the skills of science. You will be asked to assess your ability and you will receive feedback on your progress. The whole purpose of this is so that you can improve and grow in your abilities.

The method used to assess your ability in each of these skills involves using a level of performance. There are five possible levels. Level 5 is the top level of performance. It describes work that would be done at a college or university calibre. Since you are a high school student, it is reasonable to assume that you will likely be operating at levels 2, 3, or 4 in most of the skills. It is normal to be performing at different levels for some of the science skills.

To familiarize yourself with the differences between each of these levels, read the descriptions for each level as they are applied to each of the six science skills. The descriptions can be found in the Appendix.

PATHWAYS

If you have had experience from previous science courses at assessing your levels of performance for the different science skills, skip ahead to the Follow-up Activities at the end of this section. If you need further explanation of how the levels of performance relate to the science skills, complete the exercises that follow.

9. Ravi and Dietmar are each given the task of determining the height of the gymnasium's ceiling. The students are told to answer to the nearest centimetre. Both students are told that they will be assessed on the following skills:

   - initiating and planning
   - collecting and recording

   They hand in the following reports.

Height of the Gymnasium Ceiling

by Ravi

Initiating:

To determine the height, I decided to consult an expert. I thought that the best thing to do was to look up the answer on the school's blueprint. Mr. Martin, the Head Custodian, keeps these plans in his office, so I went to see him.

Collecting and Recording:

Mr. Martin let me look at the blueprint, but it was only a floor plan. The part of the plan with heights was missing – the basketball coach took it for the installation of new backboards. Mr. Martin told me that the ceiling was about 8 m high. He must know!

So, the gymnasium's ceiling is about 8 m high.

My Plan to Measure Height

Initiating:

To solve this problem I decided to count the cement blocks up the gym wall. I counted thirty-nine blocks.

Then I carefully measured one block. It was exactly 19.7 cm high.

So, the height of the gymnasium's ceiling can be calculated as follows:

$$39 \times (19.7\ \text{cm}) \doteq 768\ \text{cm}$$

The gymnasium's ceiling is about 768 cm high.

Dietmar

---

a. At what level would you assess Dietmar and Ravi's reports in terms of initiating and planning? Copy the following headings into your notebook. Be careful to leave enough space under each heading to record your answers. Explain your answers by referring to the information in the Appendix.

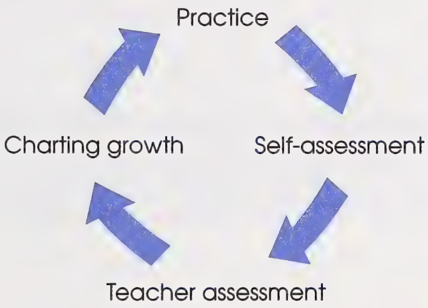
Level of Initiating and Planning	
Ravi	**Dietmar**

b. At what level would you assess Dietmar and Ravi's reports in terms of collecting and organizing? Copy the following headings into your notebook. Be careful to leave enough space under each heading to record your answers. Explain your answers by referring to the descriptions in the Appendix.

Level of Collecting and Recording	
Ravi	**Dietmar**

Ravi and Dietmar, like everyone else, can improve their abilities in these skills. Their levels of performance should not be interpreted as a grade, but rather as valuable feedback to help them begin to realize what they need to do to improve. The important thing here is not the level itself, but how much they can improve and grow in each skill category.

To help you improve and grow in your abilities with these skills, a strategy has been developed for this course.



Practice

Whenever an opportunity to practise one of the science skills arises, you will see an icon like the one shown in the left margin. Note that the names of the skills have been shortened to one word. The skills that you will practising will be checked off within the icon. If you were doing the same task as Ravi and Dietmar, you would see the first two skills checked off in the icon.

Science Skills
☑ A. Initiating
☑ B. Collecting
☐ C. Organizing
☐ D. Analysing
☐ E. Synthesizing
☐ F. Evaluating

Self-Assessment and Teacher Assessment

Some of the questions in the Assignment Booklets will allow you to use a skill. You will be asked to assess your level of performance after you have answered the question. You will record your self-assessment in an icon like the one shown below. Record your self-assessment in the first columns of boxes.

Evaluate your skill level in the appropriate self-assessment skill boxes according to the science skills framework.

	Self	Teacher		Self	Teacher		Self	Teacher
A. Initiating	4		**B. Collecting**	3		**C. Organizing**		
D. Analysing			**E. Synthesizing**			**F. Evaluating**		

In this case, you would have assessed yourself as performing at level 4 in initiating and level 3 in collecting.

The Assignment Booklets are evaluated by a teacher. When grading a question that involves science skills, the teacher will assess your ability and record what is believed to be your level of performance. This will be recorded in the same icon as your self-assessment. Note that the skill level indicated by the teacher is **not** reflected in the mark of the question. The purpose of the skill assessment is to encourage you to grow in your abilities.

Evaluate your skill level in the appropriate self-assessment skill boxes according to the science skills framework.

	Self	Teacher		Self	Teacher		Self	Teacher
A. Initiating	4	3	**B. Collecting**	3	3	**C. Organizing**		
D. Analysing			**E. Synthesizing**			**F. Evaluating**		

In this case, the teacher assessed you to be at level 3 in the skill of initiating and planning and at level 3 in the skill of collecting and recording. Note that the self-assessment agreed with the teacher assessment in ability to collect information, but differed in terms of the assessment for initiating and planning.

10. Why is it worthwhile for you to assess your own science skills in the Assignment Booklets?

Charting Growth

The whole purpose of identifying science skills with these icons is to encourage your development and growth in each of the science skills. In the examples given, collecting and initiating were assessed. The self-assessment and the teacher assessment both showed collecting to be at level 3; therefore both agree that improvement is necessary. The self-assessment showed initiating to be at level 4, while the teacher assessment showed initiating to be at level 3. In this case, your initiating skills are not as developed as you had thought. Improvement is needed.

This feedback from the assessments is valuable and needs to be charted over time. As you progress through the course, you will be practising the same skills throughout each module. To keep track of this growth, record **both** the self-assessment and the teacher assessment on the spreadsheet found in the Module 9 Assignment Booklet.

11. Turn to your Module 9 Assignment Booklet and find the spreadsheet for recording the assessment of science skills.
    a. When you get your assignments back, what two assessments do you record on the spreadsheet?
    b. What is the advantage of recording all the assessments from the whole course on one spreadsheet?
    c. Why is the spreadsheet located in the Module 9 Assignment Booklet?

Check your answers by turning to the Appendix, Section 1: Activity 4.

Follow-up Activities

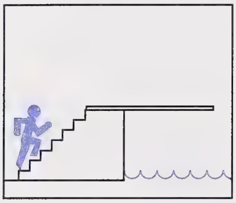
If you had difficulties understanding the concepts in the activities, it is recommended that you do the Extra Help. If you have a clear understanding of the concepts, it is recommended that you do the Enrichment.

Extra Help

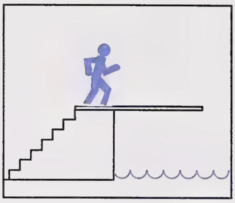
The main idea of this section is that work done on an object gives it energy which can transform from one kind to another.

1. Look at the following pictures and describe the work done, the type of energy, or the energy conversion that is occurring.

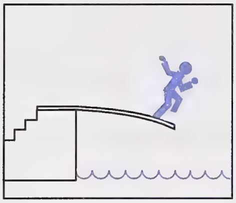
a.



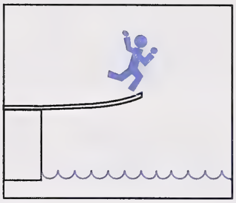
b.



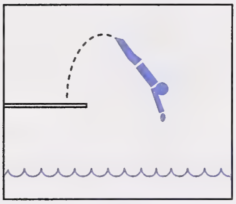
c.



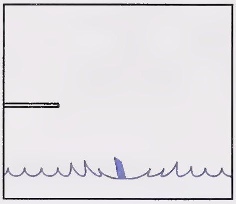
d.



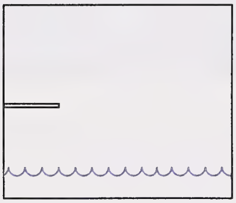
e.



f.



g.

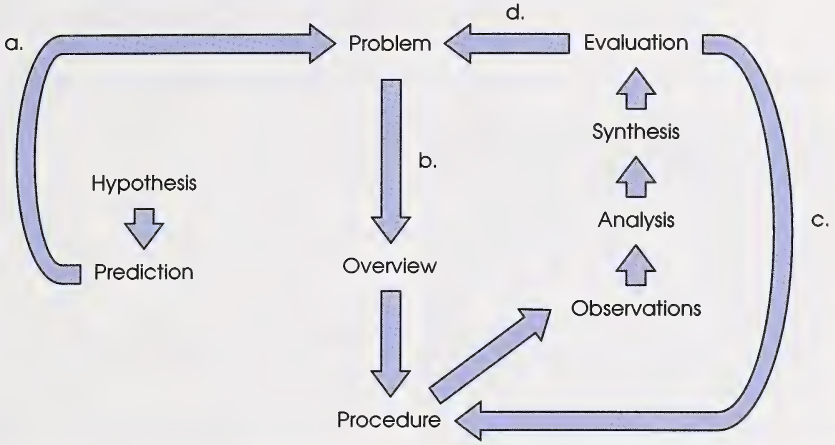


2. A slingshot is used to shoot a 1.00-kg water balloon high in the air. An average force of 150 N is put on the slingshot as it is stretched out a distance of 2.80 m. Find the balloon's initial velocity and the height that it should reach. You can use either one of the following two methods:

Method 1: Find the work done and use this to determine the kinetic energy of the balloon and its speed. The kinetic energy can be equated to the potential energy, allowing the height to be calculated.

Method 2: Set the work done equal to the kinetic energy and potential energy, and then algebraically solve for what you need.

3. An experiment follows a set of processes in order to answer a question. The order may vary a bit. Look at the diagram and write a statement that represents what thoughts or actions are occurring at each of the labelled arrows.



Check your answers by turning to the Appendix, Section 1: Extra Help.

Enrichment

Do **one** of the following questions.

1. The fluid model of heat is called the caloric theory. Research the downfall of the caloric theory and how it was replaced by the heat theory of today.

2. One reason that the gravitational constant that you calculated earlier in this section was off by so much is that the marble was rotating and the results were affected by rotational energy. Look over your data again while keeping this in mind. Here is some theory of rotation dynamics that pertains to the experiment.

No Rotation	**Rotation**
Mass (m)	Moment of inertia (I)
Velocity(v)	Angular velocity (ω)
Kinetic energy $\left(\frac{1}{2}mv^2\right)$	Rotational energy $\left(\frac{1}{2}I\omega^2\right)$

For a rolling marble, the angular velocity is equal to $\frac{v}{r}$ and its moment of inertia is $I = \frac{2}{5}mr^2$.

Including rotational energy, you have two kinds of energy in motion – rotational and kinetic.

$$\overset{\text{Total energy at the start}}{mgh} = \overset{\text{Kinetic energy}}{\frac{1}{2}mv^2} + \overset{\text{Rotational energy}}{\frac{1}{2}I\omega^2}$$

$$mgh = \frac{1}{2}mv^2 + \frac{1}{2}\left(\frac{2}{5}mr^2\right)\left(\left(\frac{v}{r}\right)^2\right)$$

$$mgh = \frac{1}{2}mv^2 + \frac{1}{5}mv^2$$

$$mgh = \frac{7}{10}mv^2$$

Use this new equation to re-evaluate the experiment. How do things look now?

Check your answers by turning to the Appendix, Section 1: Enrichment.

Conclusion

In this section you have seen how the problem-solving strategies and the skills of science can be used to investigate energy conversions for a projectile. You should have noticed that there's going to be much more to Physics 30 than quickly calculating a number that correctly answers a question. The strategies and skills that were introduced in this section will be practised throughout the course.

In the next section you will combine these skills with one of the most important ideas in physics to produce a very powerful approach to problem solving.

Assignment Booklet

ASSIGNMENT

Turn to your Assignment Booklet and do the assignment for Section 1.

Section

2 Exploring Energy Systems

WESTFILE INC.

It takes a special breed of person to be a mountain climber. The requirements are a high level of physical fitness, specialized training and skills, good equipment, and a strong desire to explore the unknown. The other key ingredient is courage. As one climber once remarked, "It's not the fear of falling that bothers me – it's that sudden stop at the bottom!"

How would you like to be the person in the photograph? Would you have what it takes to continue to explore the side of the mountain?

You may not be ready to explore mountains, but you are ready to explore one of the most important ideas in the field of physics. The skills and training from your previous courses and Section 1 have prepared you for this undertaking.

In this section you will compare and contrast the different types of systems that could be used for exploring energy. You will investigate the energy conversions that occur on an air table, as well as those that occur for a mass on a spring. Then you will learn to apply what you have learned to a wide variety of energy systems by using a new approach to problem solving.

Activity 1: Describing Energy Systems

Imagine yourself on a hot summer day at the beach. You feel thirsty so you reach into your knapsack for a can of pop. You open the can and take a long drink, only to discover that the pop is warm. What a disappointment! Instead of cool and refreshed, your throat feels the mild burn from the carbonation.

This whole situation can actually be explained by thinking about kinetic and potential energy. The only trick is to imagine the kinetic and potential energy of molecules. The following steps show what is happening on the molecular level:

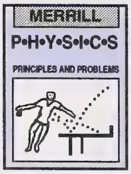
temperature – a measure that indicates the average kinetic energy of an object's molecules

- The cells in your mouth and throat tell you that the pop is warm. In energy terms, the molecules of pop are moving too fast and have too much molecular kinetic energy. The way you could measure this is by taking the **temperature** of the pop. However, it's unlikely that you carry a thermometer to the beach. All you want is a cold drink. In other words, you want to lower the temperature of the pop by taking away some of the kinetic energy of its molecules. How can you do this?
- You notice that the person sitting beside you has a bag of ice in a cooler. You borrow some ice cubes and put them into a glass with your pop. In a few minutes the drink is much cooler because the molecules of pop are slowing down (losing some of their kinetic energy). Where does this energy go? The energy goes into melting the ice by increasing the potential energy of the water molecules in the ice. As the water molecules in the ice gain more potential energy, they break free of the solid ice and join the drink as liquid water.

thermal energy – the total energy (both kinetic and potential energy) of an object's molecules

1. The term **thermal energy** is used to describe the total of the kinetic and potential energy of an object's molecules. Why not simply use the terms *kinetic* and *potential energy*?

A more complete review of thermal energy and how it can be transferred between objects can be found on pages 242 to 244 of your textbook. Read these pages and then answer the following questions to check your understanding.

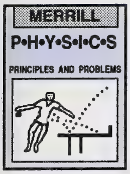


2. Describe the three ways in which thermal energy can be transferred between objects. Refer to the glass of pop on the beach to illustrate each method.
3. Which has more thermal energy, a can of warm pop or a lake filled with cool water? Explain your answer carefully.

Check your answers by turning to the Appendix, Section 2: Activity 1.

heat – the flow of thermal energy from a region of high temperature to a region of low temperature

You may be surprised that the word **heat** has not been used yet in the discussion of the warm pop on the beach. The reason is that the word *heat* has a very special meaning in physics, and it's easy to use this term incorrectly. To see how the term *heat* relates to the concepts of thermal energy and temperature, read pages 245 to 247 of your textbook.



4. What is the lowest possible temperature?
5. Use the definition of *temperature* to explain why the Kelvin temperature scale is less arbitrary than other scales.
6. Explain why it's actually incorrect in physics to say that an object **has** heat.

Check your answers by turning to the Appendix, Section 2: Activity 1.

system – a defined collection of objects to be studied

Now that you have reviewed the ideas of thermal energy and heat, you can begin to see how difficult it is to have a **system** that conserves energy. The flow of thermal energy in the form of heat is very difficult to control since it requires the regulation of energy on the molecular level.

isolated system – a system in which external forces do not act, so energy is not allowed to enter or leave the system

The best place to start putting all these ideas together is to define the kind of system that will allow energy to be conserved and to compare this system to others.

The term *conservation of energy* has a very specific meaning.

In a **closed**, **isolated** system, the total amount of energy is constant.

closed system – a system in which matter is not allowed to enter or leave the system

This means that if you enclose something in a container that won't let energy and mass in or out and measure the energy content inside, you should always get the same total energy. The kinds and amounts of each kind of energy you find can change from one to another, but the total remains constant. However, isolating a system is not easy. A thermally insulated bottle comes close to being an isolated system. A good thermally insulated bottle can keep foods and drinks hot or cold for long periods of time since heat can't enter or leave easily. A space station orbiting the earth is another example of an almost isolated system. The biggest isolated system of all is the universe itself. This means that a gain of energy at some place in the universe means a loss somewhere else!

open system – a system in which matter is allowed to enter or leave the system

There's one last point to make. In 1905 Albert Einstein demonstrated that mass is a form of energy. His equation that describes this is shown.

$$E = mc^2$$

In light of this information, look at the definition of a closed system.

Closed system – one that allows no mass to enter or leave, but that does let energy enter and leave

If mass and energy are equivalent, and if energy is entering or leaving the system, shouldn't mass also be entering or leaving the system?

?

The definition of a closed system needs to be adjusted a bit in light of this evidence. A closed system will be defined as one in which no **appreciable** amount of mass (matter) enters or leaves. This brings theory and practice in line, as the mass loss due to the mass-energy equivalence is extremely small.

7. Determine whether the following systems are open or closed. Concisely explain your answers.

   a. A car drives down a road. Consider the car to be the system.

   b. A muscle cell contracts in a person's arm. Consider the muscle cell to be the system.

   c. An apple falls from a branch to the ground. Consider the apple to be the system.

8. For each of the cases in the previous question, list some energy conversions that occur within the system and state whether or not the system is isolated.

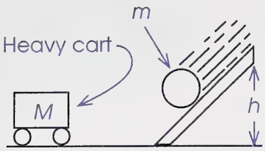
Check your answers by turning to the Appendix, Section 2: Activity 1.

The more complex a system is, the harder it is to analyse. In order to examine energy conservation in a system, you need to do two things:

- Try to isolate and close the system as best you can.
- Keep the system as simple as possible.

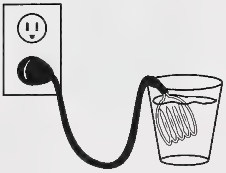
9. Here are some examples of simple systems that might be used to investigate energy conservation. Explain how they might be used to achieve this purpose. Include algebraic equations if you can.

a.



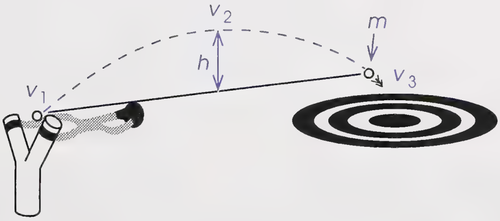
A large steel ball bearing rolls down a ramp and collides with a heavy cart that rests on the earth.

b.



An insulated cup with water contains a 50-W electric heater which adds thermal energy to the water.

c.



A slingshot shoots a rock which follows a projectile path towards a target on the earth.

Check your answers by turning to the Appendix, Section 2: Activity 1.

You probably noticed when you checked your answers to the previous question that frictional effects and the losses of thermal energy had to be assumed to be small in order for the energy conversion to be studied in a simple way. The special equipment used in the next investigation will help you keep friction to a minimum.

Activity 2: Air-Table Energy Systems

Science Skills

- ☑ A. Initiating
- ☑ B. Collecting
- ☑ C. Organizing
- ☑ D. Analysing
- ☑ E. Synthesizing
- ☑ F. Evaluating

In the last activity you read and thought about energy systems. In this activity you will investigate an energy system.

Investigation: Conservation of Energy on an Air Table

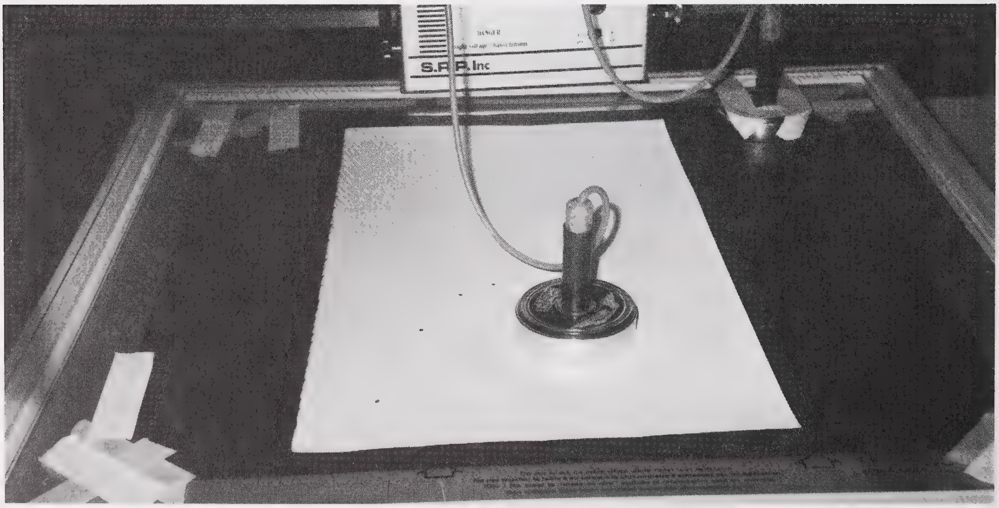
Purpose

In this investigation you will collect data to explore the relationships between the kinetic, potential, and total energy of a puck as it moves up and down an air table.

Background Information

The goal of this investigation is to collect data about the conversion of potential energy to kinetic energy. So it makes sense that other forms of energy, such as heat and sound, which are usually created through frictional effects and are very difficult to measure, should be kept to a minimum. This requires special equipment.

The air table is a device that allows a puck to travel on a cushion of air, making frictional effects very small. Unlike the kind of table that is used in air-hockey games, it is the puck that supplies the air through an attachment to an air compressor. The puck is also attached to a high-voltage spark timer that emits a spark from the bottom of the puck at very precise intervals. This means that it can leave a trail of dots which accurately records its position at different times. The following photograph shows a puck on an air table and the kind of trail left by the puck as it moves across a table.



In this investigation you will set up the air table so that its surface is an inclined plane. The puck will be launched from the lower left corner of the table towards the high end and slightly to the left. The result will be a parabolic trajectory characteristic of projectile motion. The trail of dots will be used to make measurements of distance, speed, and height. Energy calculations will be done and a graph showing the changing energy values will be made.

1. Write a prediction for this investigation. Be sure to include a description of the closed, isolated system that you will be studying.

Check your answers by turning to the Appendix, Section 2: Activity 2.

PATHWAYS

If you have access to an air table in a supervised lab, do Part A.
If you do not have access to an air table, do Part B.

Part A

Materials

You will need the following materials for this investigation:

- an air table in a supervised science lab
- a piece of newsprint paper – approximately 30 cm × 40 cm
- masking tape
- a few books
- a metric ruler
- a balance

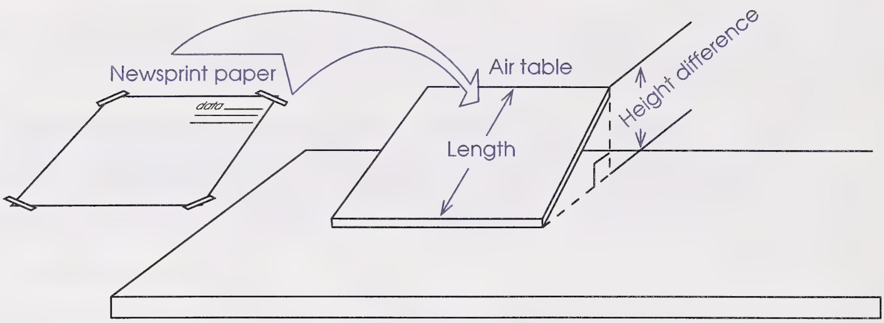
Procedure and Observations

- Read the entire Procedure and Observations section before you begin. You will be asked to write your observations onto your piece of newsprint as you follow the procedure. A sample of the completed data will be included in the Appendix for your reference.

Caution

- Ask the instructor or supervisor of the lab to demonstrate the safe operation of the air table. Great care must be exercised when using the air table because the sparking device operates at uncomfortably high voltages.

- Prepare the air table by placing a few books under one side to produce an inclined surface. The books should produce a height difference of about 10 cm.
- Measure the height difference between the high and low sides of the air table. Record this value on the top right corner of the newsprint paper.



- Measure the length of the table down the incline. Record this value on the top right corner of the newsprint paper.
- Measure the puck's mass. Record this value on the top right corner of the newsprint paper.
- Tape the sheet of newsprint paper to the air table.
- **Do not** turn on the spark timer.
- Turn on the air supply and practise gently launching the puck up the incline and slightly to the side. The goal is to have the path of the puck follow the parabolic path characteristic of projectile motion while still on the piece of paper.
- Set the spark timer to 0.100 s (100 ms).
- Turn on the power to the spark timer. Using the safety techniques demonstrated earlier by your instructor, launch the puck through a projectile path.
- Hold the puck at the top of the table (beside the parabola) and let it go. This will help you to establish true horizontal and vertical. Your data should look similar to the test data shown on the tear-out page in the Appendix.
- Using your vertical dots as a guide, draw a horizontal line below your lowest good point and label this as the reference level with zero potential energy. (Using an underlay of graph paper will help you do this.)
- Do the Analysis questions which follow Part B.

End of Part A

Part B

Procedure

- You have been provided with sample data for the procedure outlined in Part A. Read the procedure for Part A so that you understand how the data was collected.

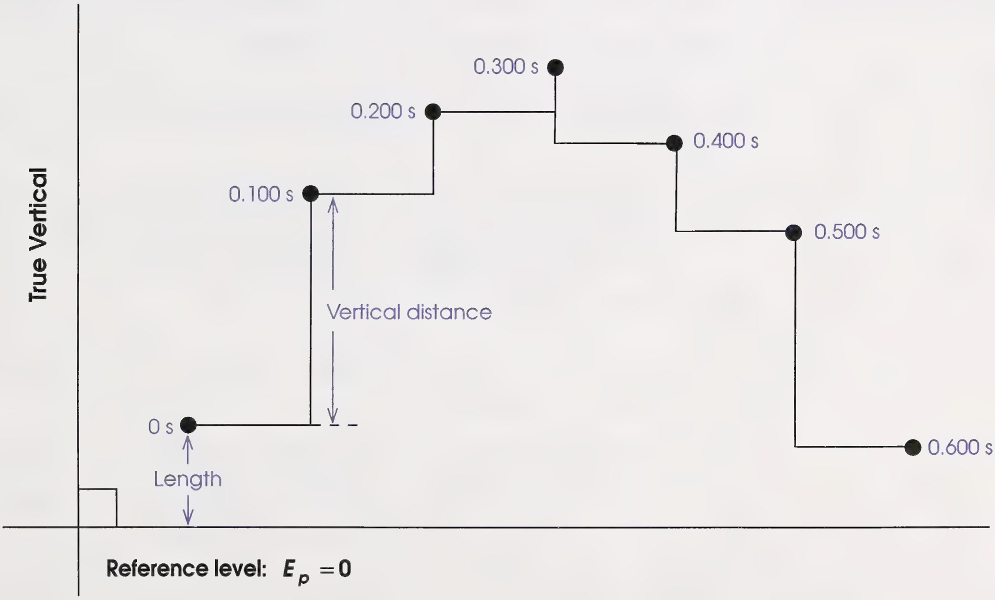
- You will find the air-table data for this experiment in the Appendix. Carefully pull out this page. Make sure the title on the pull-out page matches the title of this investigation.

End of Part B

Analysis

2. Calculate the angle of incline of the table.

The projectile motion of the puck involves both a vertical motion and a horizontal motion. The analysis that follows will involve calculating energy conversions for the **vertical motion only**. Refer to the following diagram as you complete the analysis.



3. If frictional effects have been made very small, what should be true about the kinetic energy in the horizontal direction?

- Label each of the dots above the zero potential energy line by writing a time beside it. Label the first dot as 0 s, the second dot as 0.100 s, the third dot as 0.200 s, and so on until all the dots are labelled.

- Place a piece of graph paper under the air-table dots. Carefully align the grid with the true vertical and true horizontal lines. Using a ruler and the graph paper underlay, connect the dots with horizontal and vertical lines in a staircase pattern.

- Copy the following headings into your notebook. Be careful to leave enough space under each heading to record your answers. Call this Table 1. Complete this chart as you do the following steps. A completed version of this chart will be included in the Appendix for your reference.

Table 1

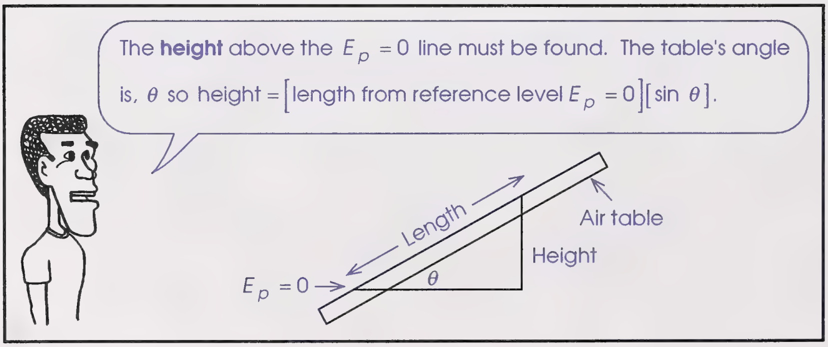
Time (s)	Vertical Distance from Previous Dot (m)	Average Vertical Speed in Interval (m/s)	Length from Reference Level (m)	Height Above Reference Level (m)

- Record the time for each of the dots on the chart.

- Measure the vertical distance from each dot to the previous dot. Record these values on the chart.

- Calculate the average vertical speed of the puck between dots. Recall from Physics 20 that the average speed for a time interval can be calculated using $v_{\text{ave}} = \frac{\Delta d}{\Delta t}$, where Δt equals the time between intervals. Record these calculated values in the data chart.

- Measure the length from the reference level, where $E_p = 0$, to each dot and record these distances in the data chart.


The **height** above the $E_p = 0$ line must be found. The table's angle is, θ so height $= [\text{length from reference level } E_p = 0][\sin\theta]$.
Length
Air table
Height
θ
$E_p = 0$

- Calculate the **height** above the reference level using the lengths above the $E_p = 0$ line for each of the dots and the angle of the table. Record these values on the data chart.

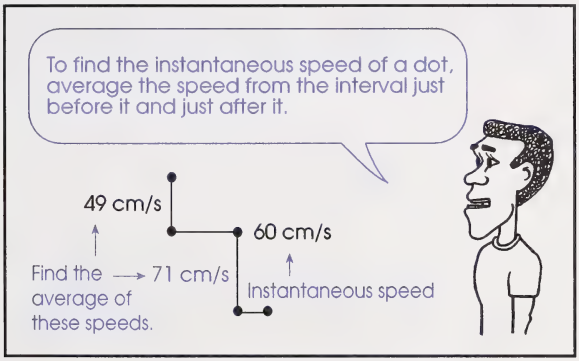
Check your answers by turning to the Appendix, Section 2: Activity 2.

- Copy the following headings into your notebook. Be careful to leave enough space under each heading to record your answers. Call this Table 2. Complete the chart as you do the following steps.

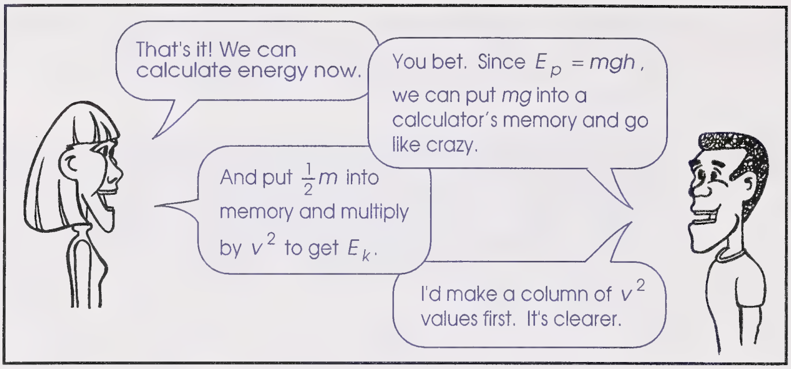
Table 2

Time (s)	**Height Above Reference Level (m)**	**Instantaneous Speed (m/s)**	**Speed Squared (m^2/s^2)**	**Potential Energy (J)**	**Kinetic Energy (J)**	**Total Energy (J)**

- Copy the values for time and height from Table 1 into the data chart.


To find the instantaneous speed of a dot, average the speed from the interval just before it and just after it.
49 cm/s
60 cm/s
Find the average of these speeds.
71 cm/s
Instantaneous speed

- Find the instantaneous speed for the puck at each dot. Record these values on the data chart. Note that since this technique requires an interval both before and after the dot, the first dot and last dot will not have values on the chart.


That's it! We can calculate energy now.
You bet. Since $E_p = mgh$, we can put mg into a calculator's memory and go like crazy.
And put $\frac{1}{2}m$ into memory and multiply by v^2 to get E_k.
I'd make a column of v^2 values first. It's clearer.

- Calculate the value of speed squared of the puck at each dot. Record these values on the data chart and then calculate the kinetic energy of the puck for each speed. Be careful to record the kinetic energies under the proper column. Note that the first dot and last dot will not have values.

- Calculate the values of potential energy for the puck at each dot. Record these values on your data chart under the appropriate heading. Note that you don't need to provide values for the first and last dots.

- Calculate the value of total energy for the puck at each dot. Record these values on the data chart. Note that you won't provide values for the first and last dots.

4. Make a graph of energy versus time. Include potential, kinetic, and total energy on the same graph. Use different colours of ink or pencil leads to differentiate the particular sets of data. Use the standard graph paper with 1-cm squares. Be sure to leave at least ten squares on the horizontal axis and at least twelve squares on the vertical axis. Scale the axes so that the data points use most of the grid.

Conclusions

5. How did your prediction hold up? Is it verified or falsified?

6. Describe the energy conversions that are summarized by the graph.

7. An air table and spark timer is an expensive apparatus. Describe a few things it does to isolate the system you investigated.

Check your answers by turning to the Appendix, Section 2: Activity 2.

The last investigation showed that the total energy of the air-table system remained constant. In physics, the term *conserved* is used to describe this type of circumstance. Note the differences in the meanings of the word *conserved* between physics and everyday speech. In everyday life, things that are conserved are saved and used wisely. In physics, quantities that are conserved have a constant value for all the trials investigated. As you progress through the rest of the course, you will investigate the conservation of other quantities, such as momentum and charge. The fact that these quantities are conserved is enormously important to the study of physics.

Can energy be shown to be conserved in other circumstances? In the next activity you'll have an opportunity to explore this question.

Activity 3: Mass-on-a-Spring Energy Systems

In the last activity you were able to complete an investigation that showed how energy was conserved for a puck on an air table. In this activity you will see if this idea can be extended to other systems.

One system that's a good candidate for investigation is a mass on a spring. This system can be investigated directly and is capable of producing good measurements for the energies involved. However, before you study the energy conversions of a mass on a spring, it's a good idea to learn something about springs themselves and to review some ideas about simple harmonic motion.

Investigation: Properties of a Mass on a Spring

Science Skills

☐ A. Initiating
☑ B. Collecting
☑ C. Organizing
☑ D. Analysing
☐ E. Synthesizing
☐ F. Evaluating

Purpose

In this investigation you will discover the fundamental properties of a mass on a spring.

Materials

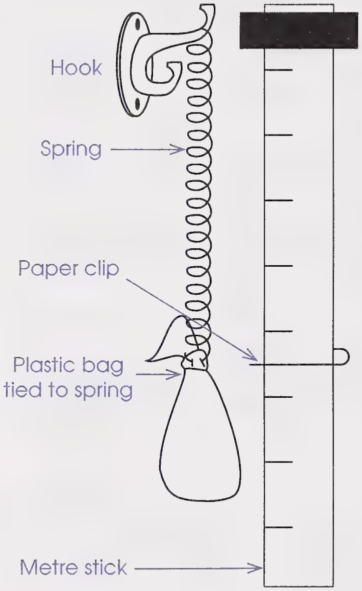
You will need the following materials for this investigation:

- a spring
- a set of identical masses, each ranging from 100 g to 150 g (If you don't have access to a school science lab, you can use $\frac{1}{4}$-lb blocks of margarine for masses. The margarine blocks can be put in a plastic bread bag and tied to the lower hook on the spring.)

- a measuring tape or metre stick
- a paper clip
- a stand to support the spring (If you don't have access to a school science lab, you can use a coat hook on a wall.)
- a stopwatch

Procedure and Observations

- Read the entire Procedure and Observations section before you begin. You will be asked to write your observations into a data chart as you do the procedure. A complete data chart will be included in the Appendix for your reference.



The paper clip acts as a marker to indicate the position of the lowest part of the spring. The metre stick will likely have to be supported by a chair and then taped at the top to make sure that it is secure.

- Copy the following headings into your notebook. Be careful to leave enough space under each heading to record your answers.

Mass on Spring (kg)	Weight on Spring (N)	Paper Clip Position (cm)	Displacement from Unloaded Position (m)	Time for Fifty Oscillations (s)	Period of Vibration (s)	Period Squared (s^2)

unloaded position – the location of the lowest coil of a vertical spring when no mass is attached

- Measure the position of the bottom of the lowest point of the spring on the metre stick. This position will be known as the **unloaded position**. Record this position on the data chart. Note that since the mass in the bag is zero, the weight in the bag is also zero. Also note that since the bag is in the unloaded position, the displacement from the unloaded position is zero.
- Add a single mass to the plastic bag. If you use a margarine block, the mass will be approximately 0.114 kg.

equilibrium position – the location where the net force acting on a system is zero

- Note that the mass will stretch the spring until the force supplied by the spring is balanced by the force of gravity. This position is called the **equilibrium position** because the forces on the mass are in equilibrium.
- Record the equilibrium position and calculate the displacement from the unloaded position and the weight of the mass on the spring.
- Pull down the end of the spring and release it so that it vibrates up and down. A complete vibration or oscillation occurs when the bottom of the spring goes from its lowest point to its highest point and then back to its lowest point again.
- Measure how long it takes the spring to make fifty oscillations. Record this value on the data chart.
- Repeat the previous part of the procedure by using two masses and then three masses and so on, until you are using six masses. For each trial, record the data on the data chart.

Analysis

simple harmonic motion – the motion exhibited by any vibrating system in which a force restores the system to its equilibrium position; the force is proportional to the displacement but acts in the opposite direction

You should recall from Physics 20 that a special type of vibratory motion can occur. This kind of motion is called **simple harmonic motion**. Simple harmonic motion could only be said to be occurring for the mass on the spring if the following equation was satisfied.

$$\text{Restoring force exerted by spring} \longrightarrow \boxed{\vec{F}_s = -k\vec{x}} \longleftarrow \text{Displacement of spring from the unloaded position}$$

Spring constant – indicates stiffness of spring

The negative sign means that the restoring force acts opposite to the displacement.

This equation is called Hooke's law. In this vector equation the negative sign is used to indicate direction. The equation simply says that if a 1-N force causes 4 cm of stretch, a 2-N force should cause 8 cm of stretch, and a 3-N force should cause 12 cm of stretch. Your data can indicate this to you. The first thing to do is to convert this vector equation to a scalar one so that you can graph the data.

$$\boxed{\vec{F}_s = -k\vec{x}}$$

$$\Big\downarrow$$

Deal only with the magnitude of the restoring force and the displacement.

$$\boxed{\left|\vec{F}_s\right| = kx}$$

1. Make a graph of the displacement versus the force for the spring. Be sure to put the manipulated variable on the *x*-axis and the responding variable on the *y*-axis. Use the standard graph paper with 1-cm squares. Be sure to leave at least ten squares on the horizontal axis and eleven squares on the vertical axis.

2. Calculate the slope of the graph and use the slope to calculate the spring constant.

3. Is the motion of the mass on the spring simple harmonic motion? Explain your answer.

There is another way to calculate the spring constant that is also based on the simple harmonic motion of a mass on a spring. The following equation describes this technique.

Period of vibration – time for one complete oscillation

$$\boxed{T = 2\pi\sqrt{\frac{m}{k}}}$$

Mass vibrating on the spring

Spring constant

You can find the derivation of this equation in the Enrichment activities of this section.

- Calculate the period of vibration for each of the masses. Record these values on the data chart.

4. How could you graph the period and mass data to produce a straight-line graph? Answer by producing a flow chart that clearly shows how the equation $T = 2\pi\sqrt{\frac{m}{k}}$ can be manipulated into the form $y = mx + b$.

Check your answers by turning to the Appendix, Section 2: Activity 3.

5. Based on your answer to the previous question, graph the data to produce a best-fit straight line. Use the standard graph paper with 1-cm squares. Be sure to leave at least eight squares on the horizontal axis and seven squares on the vertical axis.

6. Calculate the slope of the best-fit line.

7. Calculate the spring constant from the value for slope. How does this answer compare with the earlier value for the spring constant?

Conclusions

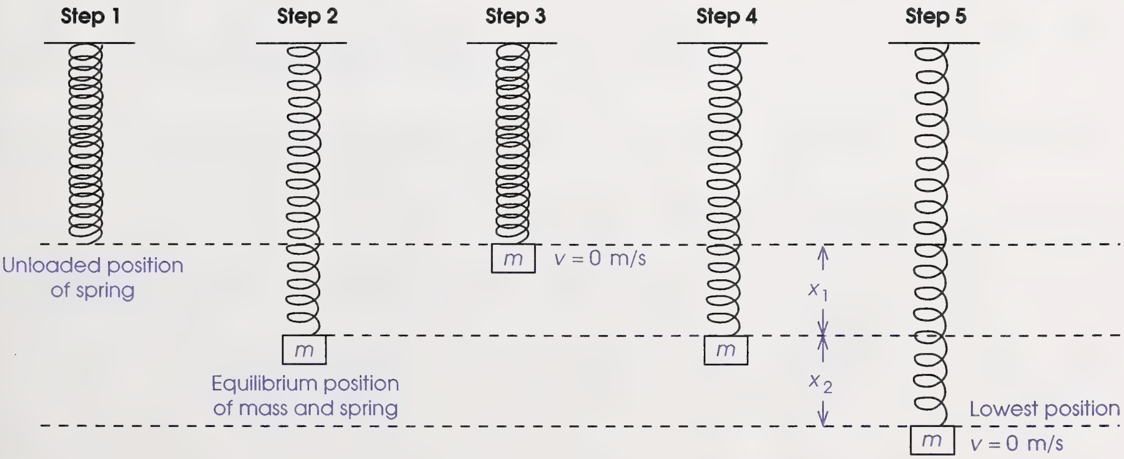
8. What evidence have you collected to support the idea that the mass on the spring is a simple harmonic oscillator?

9. What things may have contributed to errors in this investigation? List specific things for each method that was used to calculate *k*.

Check your answers by turning to the Appendix, Section 2: Activity 3.

Now that you have got some more insight into the physics of a mass on a spring, you can turn your attention to the energy conversions of a mass on a spring.

If you were to use the same apparatus as in the previous investigation, you could use the following sequence of steps to explore energy conversions for the mass on the spring.



Step 1: A spring is attached to a hook. The position of the lowest coil of the spring is recorded as the unloaded position of the spring.

Step 2: A mass is attached to the spring and is slowly lowered until the equilibrium position of the mass and spring is determined.

Step 3: The mass on the spring is raised until it reaches the unloaded position of the spring. The mass is then released from this position. For an instant the mass has no speed, but after that instant it accelerates downward as it falls.

Step 4: The mass on the spring accelerates to its former equilibrium position. The motion it has acquired carries it past this point. Once past the equilibrium position, the mass begins to slow down as the spring is stretched.

Step 5: The mass on the spring has reached its lowest position and it stops momentarily. For an instant all the energy of the system is stored in the spring.

If the spring was allowed to continue beyond Step 5, it would oscillate up and down, accelerating towards the equilibrium position and then decelerating to a stop at each end of its motion. How could this system be analysed in terms of energy?

One approach is to say that the system has only the energy stored in the stretched coils at Step 5. Since the mass has stopped, kinetic energy is zero here. Since the reference level for gravitational potential energy can be defined anywhere that's convenient, the lowest position is a good place to define gravitational potential energy as being equal to zero.

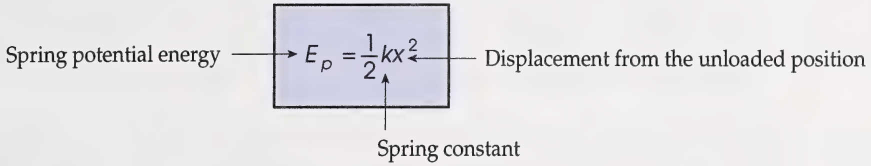
It follows that the system would have gravitational potential energy at Step 3, since this position is above the reference level. However, since the mass is not moving, kinetic energy is zero, and since the coils are in their unloaded position, no energy is stored in the spring.

10. Given the approach just described, what types of energy does the system have at Step 4?

11. How would you calculate the gravitational potential energy when the mass returns to the unloaded position, as shown in Step 3? Relate the variables listed on the diagram to the equation for gravitational potential energy.

12. How would you calculate the spring potential energy at Step 5? Use the spring constant (k) and the variables listed on the diagram to derive a new equation for the spring potential energy.

The new equation that you derived will be referred to frequently throughout this section. Be sure that you are familiar with the meaning of all the variables.



13. Show by analysing the units that $\frac{1}{2}kx^2$ will give energy units.

Check your answers by turning to the Appendix, Section 2: Activity 3.

If energy is conserved in this system, the gravitational potential energy in Step 3 should convert completely to spring potential energy in Step 5. In the next investigation you will design an experiment to test this idea.

Investigation: Gravitational Potential Energy to Spring Potential Energy

Science Skills

☑ A. Initiating
☑ B. Collecting
☑ C. Organizing
☑ D. Analysing
☑ E. Synthesizing
☑ F. Evaluating

Purpose

In this investigation you will design an experiment to verify the conversion of gravitational potential energy to spring potential energy.

14. Write up a concise description of the procedure you will use. You should include any techniques that you will use to reduce errors.

15. Use a diagram to record the measurements that you made. Calculate the energy values beside the diagram.

16. State whether or not energy is conserved. Base your answer on the results of your calculations. Account for any discrepancies in the results by listing possible sources of error.

17. Calculate the value of the kinetic energy for the mass on the spring when it was travelling through the rest position. What must you assume to be true to complete this calculation?

18. What measurement would you need to make in order to verify the previous calculation? What kind of equipment would be required?

The answers to the previous questions make an important point. If a system is one in which energy can be considered to be conserved, quite difficult problems can often be solved in a few direct steps.

The previous activities suggest an even more important implication of energy conservation. Energy conservation was shown to be valid for a puck on an air table and a mass-and-spring system. Does this mean that energy conservation can be applied to any closed, isolated system regardless of the types of energy involved?

The answer to this question is yes. For over 100 years scientists have studied thousands of different systems, involving many different types of energy, and every one of them has shown that energy is always conserved in a closed, isolated system. Since energy conservation concisely describes how nature behaves for a wide range of phenomena, it is called the law of conservation of energy.

19. Give two reasons why the law of conservation of energy is so important to physics.

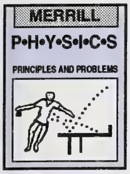
Check your answers by turning to the Appendix, Section 2: Activity 3.

In the next activity you will learn to apply the law of conservation of energy to a number of different systems.

Activity 4: Problem-Solving Techniques

Imagine that you are hired as a lab assistant in a physics laboratory. You want to do well, so you collect the data carefully and double check all your calculations. This impresses the scientists involved and they decide to reward you by showing you a technique that is guaranteed to make you much more successful in the rest of your Physics 30 course. Wouldn't that be great?

Well, the fact of the matter is that you don't have to imagine this – it is a reality now! You are now ready to learn a problem-solving technique that can be used throughout the remainder of the course. The whole key to this technique is to understand the law of conservation of energy.



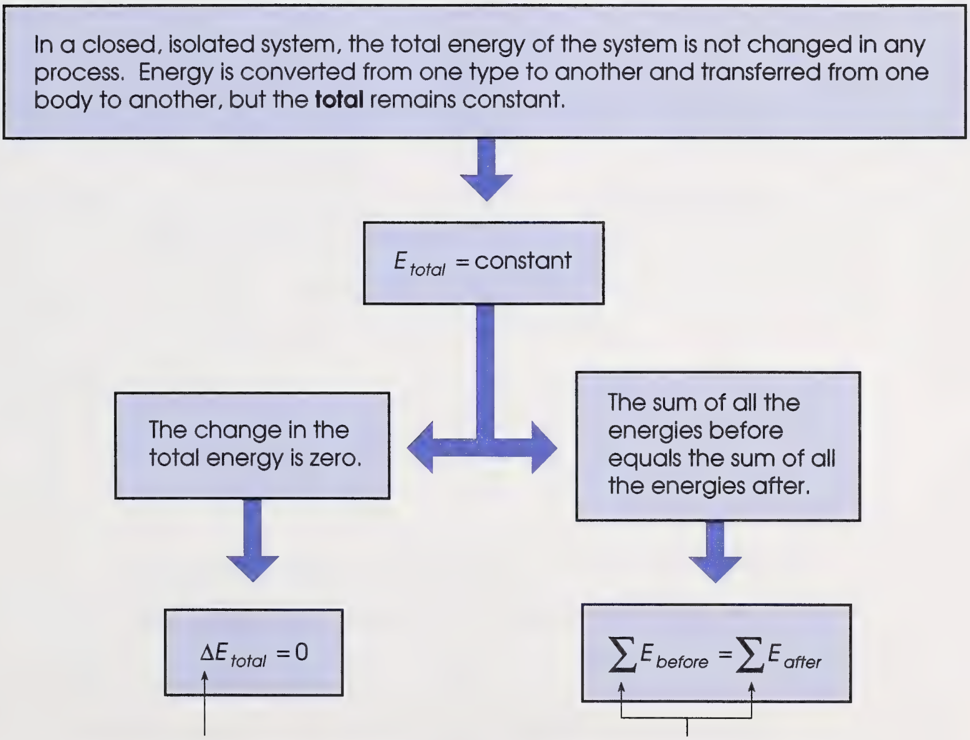
To be sure that you really understand this idea, it's a good idea to see how the textbook explains it. Carefully read page 217 and pages 227 to 229 in your textbook. When you have finished reading, answer the following questions.

1. Explain why the first hill of a roller coaster must be the highest one. Assume that the roller coaster is almost at rest at the top of the first hill.

2. Explain why the second hill of a roller coaster must be lower than the first hill. Assume the roller coaster is at rest at the top of the first hill. Use the ideas of friction and thermal energy to explain your answer.

3. The first step of the Problem-Solving Strategy on page 229 is to carefully identify the system. Why is this such an important first step?

If the problem that you are solving involves a closed, isolated system, you can use the law-of-conservation-of-energy technique. The whole key to this method is to start each solution the same way. The following flow chart shows the origin of the starting statement.



In a closed, isolated system, the total energy of the system is not changed in any process. Energy is converted from one type to another and transferred from one body to another, but the **total** remains constant.

$E_{total} = \text{constant}$

The change in the total energy is zero.

The sum of all the energies before equals the sum of all the energies after.

$\Delta E_{total} = 0$

$\sum E_{before} = \sum E_{after}$

The Greek letter delta (Δ) stands for the words *the change in*.

The Greek letter sigma (Σ) stands for the words *the sum of all*.

4. Write the sentences implied by these equations.

   a. $\sum \text{heat losses} = \sum \text{heat gains}$
   b. $\text{mass} = \text{mass}'$
   c. $\sum \text{wins} = \sum \text{losses}$

Check your answers by turning to the Appendix, Section 2: Activity 4.

Now you will see how you can solve problems using the sigma notation equation for the law of conservation of energy.

Example 1

A flower pot falls off a 3.0-m ledge. With what speed will it hit the ground, assuming air resistance is negligible?

$h = 3.0 \text{ m}$
$v = 0 \text{ m/s}$
$g = 9.81 \text{ m/s}^2$
$v' = ?$

$$\begin{aligned}
\sum E_{before} &= \sum E_{after} \\
E_p + E_k &= E_p' + E_k' \\
mgh + \frac{1}{2}mv^2 &= mgh' + \frac{1}{2}mv'^2 \\
mgh + 0 &= 0 + \frac{1}{2}mv'^2 \\
v' &= \sqrt{2gh} \\
&= \sqrt{2\left(9.81 \text{ m/s}^2\right)(3.0 \text{ m})} \\
&= 7.7 \text{ m/s}
\end{aligned}$$

There are some important things to note about this example:

- The potential and kinetic energies are both listed as energies for before and after the fall.
- The problem reduces to a more familiar form sooner or later $\left(mgh = \frac{1}{2}mv^2\right)$, but begins with a more general statement.
- This form of solution can solve **all** the energy problems that you will encounter.

- You can alo use the kinematics/dynamics material from Physics 20 to solve the same problem.

Example 2

$v_i = 0\ \text{m/s}$

$a = g = 9.81\ \text{m/s}^2$

$d = 3.0\ \text{m}$

$v_f = ?$

$$\begin{aligned} v_f^2 &= v_i^2 + 2ad \\ v_f^2 &= 0 + 2ad \\ v_f &= \sqrt{2ad} \\ &= \sqrt{2(9.81\ \text{m/s}^2)(3.0\ \text{m})} \\ &= 7.7\ \text{m/s} \end{aligned}$$

Note the similarities between Example 1, which uses the law of conservation of energy, and Example 3.

Example 3

A mass of 10.0 g is attached to a horizontal spring. The mass rests on a frictionless surface. If the spring is compressed 30.0 cm and then released, what speed will the mass have when it returns to its equilibrium position? Note that the equilibrium position and the unloaded position are the same place here.

$k = 15.0\ \text{N/m}$

$x = 0.300\ \text{m}$

$m = 0.0100\ \text{kg}$

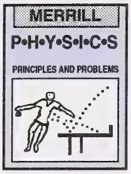
$v = ?$

$$\begin{aligned} \sum E_{before} &= \sum E_{after} \\ E_p + E_k &= E_p{}' + E_k{}' \\ \frac{1}{2}kx^2 + \frac{1}{2}mv^2 &= \frac{1}{2}kx'^2 + \frac{1}{2}mv'^2 \\ \frac{1}{2}kx^2 + 0 &= 0 + \frac{1}{2}mv'^2 \\ v' &= \sqrt{\frac{kx^2}{m}} \\ &= \sqrt{\frac{(15.0\ \text{N/m})(0.300\ \text{m})^2}{0.0100\ \text{kg}}} \\ &= 11.6\ \text{m/s} \end{aligned}$$

Note the following points from this example:

- There is a different equation for spring potential energy, but the overall method is the same.
- You can't use a kinematics approach here because the force is not constant. This means the acceleration also will not be constant.

Examples 1 and 3 demonstrate that this technique works well in very different circumstances. These examples also show that this method emphasizes the similarities between the problems, rather than the differences. This gives you a powerful tool because problems are easier to solve if they look like other problems that you have already answered. Clearly, for this idea to work, you have got to begin each solution the same way (by stating the law of conservation of energy) so you can recognize the similarities.

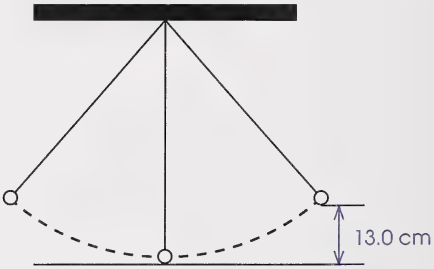


5. Solve Problems 27, 22, and 25 on page 239 of your textbook. Use the law-of-conservation-of-energy technique. Be sure to do the questions in the order indicated.

Check your answers by turning to the Appendix, Section 2: Activity 4.

How did your answers compare with the answers in the Appendix? Can you see the similarities between the solutions to the previous questions? The one place where the problems can differ from one another is in the third or fourth step, where zero values are assigned to some of the energies. Keep this in mind as you try the next problems.

6. A pendulum is pulled aside and released as shown. Find its speed at the bottom of the swing.



7. A 150-g mass is attached to a horizontal spring on a frictionless surface. The spring has a spring constant of 11.0 N/m. The mass is pulled 50.0 cm from its equilibrium position, held motionless, and then released. Find the speed of the mass when it passes through its equilibrium position again.

8. The spring that was used in the previous question is released after being stretched 50.0 cm. What speed will the mass have as it moves past a position 30.0 cm from the equilibrium point?

9. A 1.00-m pendulum is pulled aside to make a 30.0° angle with the vertical and is released. What speed will it have when the angle is 10.0°?

You may have noticed that all the questions using springs have referred to horizontal springs. This simplified the problems by removing gravitational effects. However, if you think back to the last investigation, you should be able to solve vertical spring problems too. Refer to the previous investigation as you answer the following questions.

10. A spring with negligible mass hangs vertically down from a support. There is no mass attached to the spring yet. A 655-g mass is carefully attached to the spring and is held to prevent the spring from stretching. The mass is suddenly released, causing the spring to stretch. The mass then continues to vibrate up and down with a period of 0.827 s.

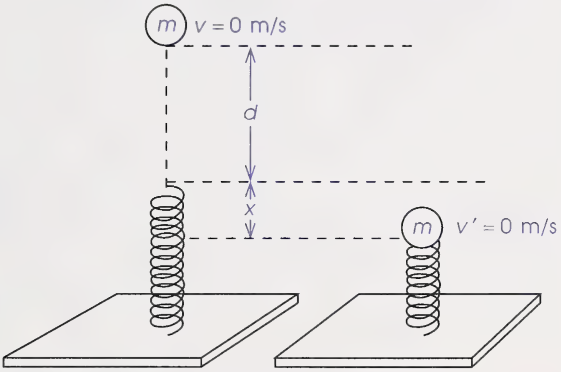
    a. Before dealing with energies, calculate the spring constant.

    b. Use the law of conservation of energy to determine the maximum distance that the spring stretched from its unloaded position.

    c. The mass will eventually come to rest and stop vibrating. Calculate how far the equilibrium position is below the unloaded point for the spring. Use Hooke's law in your solution.

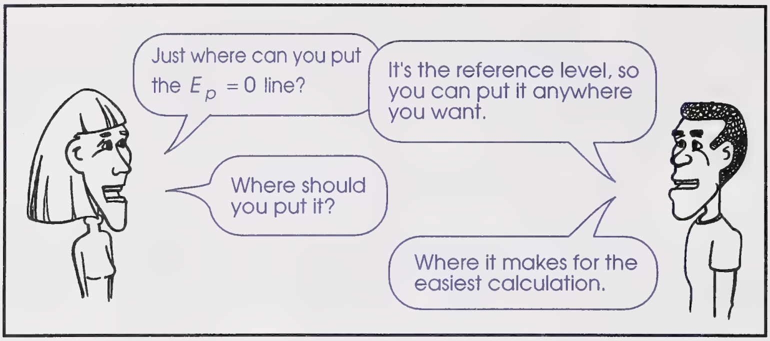
    d. How could you have answered question 10.c. using the answer from question 10.b. and your knowledge of simple harmonic motion?

11.



A ball with a mass of 0.185 kg is held motionless a distance of 35.6 cm above a spring. The ball is dropped and it compresses the spring 28.8 cm until the ball momentarily stops. Calculate the spring constant for the spring.

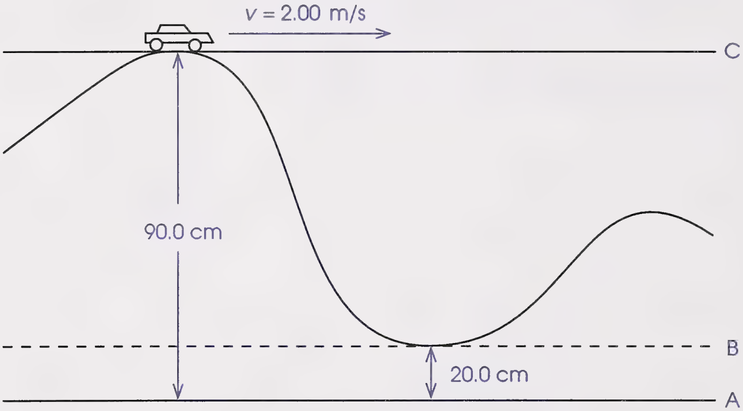
Check your answers by turning to the Appendix, Section 2: Activity 4.


Just where can you put the $E_p = 0$ line?
It's the reference level, so you can put it anywhere you want.
Where should you put it?
Where it makes for the easiest calculation.

Keep Mike's hint in mind as you look at the different methods shown in the next example.

Example

A car slides over a frictionless track as shown. What speed should it have at the bottom of the valley?



Solution

$$\sum E_{before} = \sum E_{after}$$

$$E_p + E_k = E_p' + E_k'$$

If Line A is $E_p = 0$

$$\begin{aligned}
\cancel{m}gh+\frac{1}{2}\cancel{m}v^2 &= \cancel{m}gh'+\frac{1}{2}\cancel{m}v'^2 \\
v' &= \sqrt{2\left(gh+\frac{1}{2}v^2-gh'\right)} \\
&= \sqrt{2\left[\left(9.81\ \text{m/s}^2\right)(0.900\ \text{m})+\frac{1}{2}(2.00\ \text{m/s})^2-\left(9.81\ \text{m/s}^2\right)(0.200\ \text{m})\right]} \\
&= \sqrt{17.734} \\
&= 4.21\ \text{m/s}
\end{aligned}$$

If Line B is $E_p = 0$

$$\begin{aligned}
\cancel{m}gh+\frac{1}{2}\cancel{m}v^2 &= 0+\frac{1}{2}\cancel{m}v'^2 \\
v' &= \sqrt{2\left(gh+\frac{1}{2}v^2\right)} \\
&= \sqrt{2\left[\left(9.81\ \text{m/s}^2\right)(0.700\ \text{m})+\frac{1}{2}(2.00\ \text{m/s})^2\right]} \\
&= \sqrt{17.734} \\
&= 4.21\ \text{m/s}
\end{aligned}$$

If Line C is $E_p = 0$

$$\begin{aligned}
0+\frac{1}{2}\cancel{m}v^2 &= \cancel{m}gh'+\frac{1}{2}\cancel{m}v'^2 \\
v' &= \sqrt{2\left(\frac{1}{2}v^2-gh'\right)} \\
&= \sqrt{2\left[\frac{1}{2}(2.00\ \text{m/s})^2-\left(9.81\ \text{m/s}^2\right)(-0.700\ \text{m})\right]} \\
&= \sqrt{17.734} \\
&= 4.21\ \text{m/s}
\end{aligned}$$

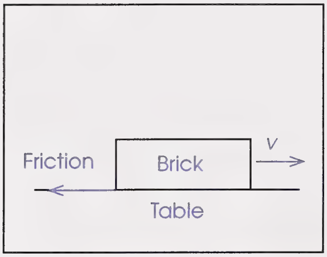
E_p can be a negative value if the height is **below** the $E_p = 0$ line.

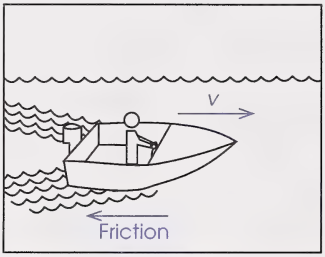
As the previous example indicates, you have some choice when it comes to the decision of where potential energy is defined to be zero. The best strategy is to choose a location that allows your calculations to work out with as few terms as possible. Keep this in mind as you try the following problem.

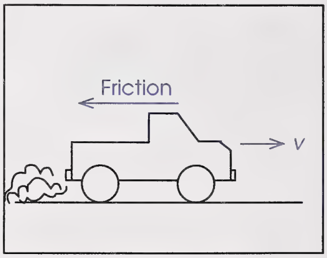
12. A ball falls past a window. It is moving at 8.8 m/s at the top of the window and the window is 1.30 m high. What speed will the ball have at the bottom of the window?

The only variation left to consider in the problem-solving technique developed in this activity is to add in the role of friction.

Friction is a retarding force that exists between any two surfaces. The surfaces may be any state of matter: solid, liquid, or gas.







If friction is a significant force in a system, the system must do work against that friction.

For example, consider a marble that is rolling across a floor. The force of friction between the marble and the floor acts to slow down and eventually stop the marble. The kinetic energy of the marble was used to do work against friction. Refer to this example as you complete the following questions.

13. What type of energy is created by the work done against friction?

14. What would you need to measure to verify your answer to the previous question? Would these measurements be easy to make?

Check your answers by turning to the Appendix, Section 2: Activity 4.

You can now extend the conservation law to include friction and work done on a system. It looks like this.

$$\sum E_{before} = \sum E_{after}$$

$$E_p + E_k = E_p' + E_k' + W' \longleftarrow \text{Work done by the system to create thermal energy}$$

Example

A 2.00-kg ball falls off a ledge that is 5.00 m high. Its speed at the bottom is 7.50 m/s. Find the average force of friction (air resistance in this case).

Solution

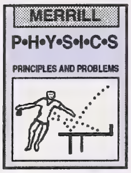
$$\begin{aligned}
\sum E_{before} &= \sum E_{after} \\
E_p + E_k &= E_p' + E_k' + W' \\
mgh + 0 &= 0 + \frac{1}{2}mv'^2 + F_f d \\
F_f &= \frac{mgh - \frac{1}{2}mv'^2}{d} \\
&= \frac{(2.00\ \text{kg})(9.81\ \text{m/s}^2)(5.00\ \text{m}) - \frac{1}{2}(2.00\ \text{kg})(7.50\ \text{m/s})^2}{5.00\ \text{m}} \\
&= 8.37\ \text{N}
\end{aligned}$$

Look at the equation in the third line of the solution.

$$\boxed{\underbrace{F_f d}_{\text{Work done against friction}} = \underbrace{\boxed{mgh - \frac{1}{2}mv^2}}_{\text{Change in energy}}}$$

This is consistent with the work-energy theorem, which says the work done by a system equals the change in the energy of that system.

Use this new version of the law of conservation of energy to solve the following problems from your textbook.



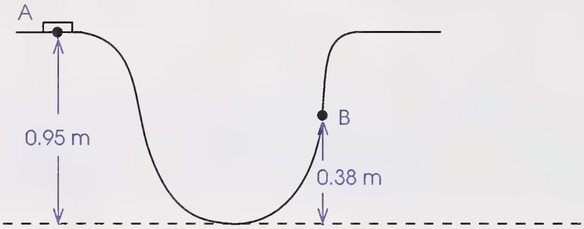
15. Do Problem 26 on page 239 of your textbook.

16. Do Chapter 11 question 4 on page 696 of your textbook.

Check your answers by turning to the Appendix, Section 2: Activity 4.

The following questions will give you a chance to integrate the ideas about work done against friction with the other ideas that you have been practising in this activity.

17. A 10.0-g disk slides over a ramp. It starts at rest at position A and stops at position B. The distance from A to B along the ramp is 1.36 m. Find the average force of friction acting here.



18. A 1400-kg car rolls 20.0 m down a driveway that is inclined at 8.00°. If a 200-N average force of friction acts here, what will the car's speed be at the bottom of the incline? Assume that the initial velocity is 0 m/s.

19. A 900-kg car brakes and stops from an initial speed of 20.0 m/s. What is the average braking force needed to stop the car in 60.0 m?

20. A dam is constructed so that 5.0 t of water per second is sent 200 m down to an electric generating station. The station produces 6.9 MW of power.

    a. How much potential energy is available for electricity production each second?

    b. How much useful energy is produced each second?

c. How much waste heat is produced in a 24.0-h period of time?

d. Efficiency is defined as the ratio of useful energy produced to energy used expressed as a percent. How efficient is this process?

21. A 7.0-t meteoroid skips through the atmosphere. While moving parallel to the ground, it slows from 1.00 km/s to 0.75 km/s. How much thermal energy is produced?

Check your answers by turning to the Appendix, Section 2: Activity 4.

Follow-up Activities

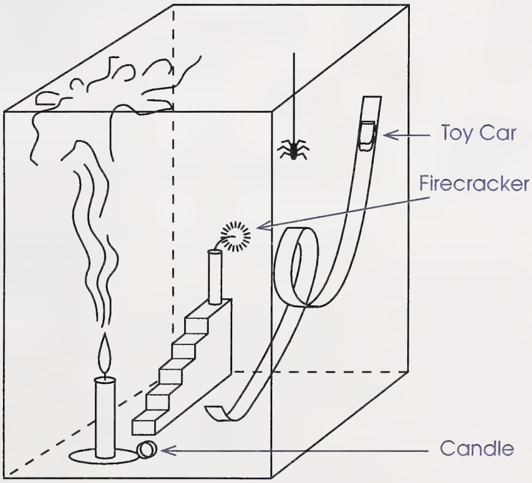
If you had difficulties understanding the concepts in the activities, it is recommended that you do the Extra Help. If you have a clear understanding of the concepts, it is recommended that you do the Enrichment.

Extra Help

1. A closed, isolated system can't change its total energy. Examine the system which is enclosed in a glass aquarium with a lid and sealed . Some of the energy conversions of this system are noted beside the diagram.

   a. Describe the energy conversions that will occur for the firecracker, the toy car, and the candle.

   b. Is this system both closed and isolated? Concisely explain your answer.



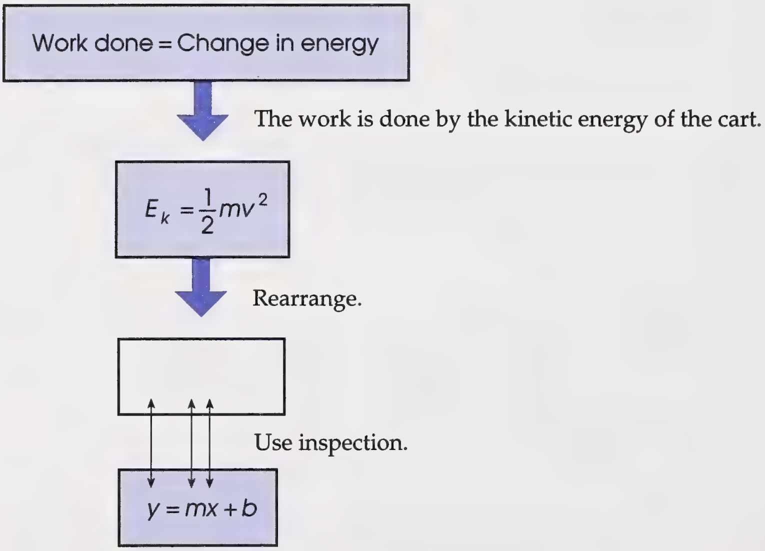
2. Hot soup eventually cools down in an insulated bottle. Where does the thermal energy go?

After an experiment is done, the data is analysed to find patterns and trends. The equations that govern the theory tested have the information in them to suggest how to straighten a graph or what a slope or an intercept means. The following question will allow you to practise these skills.

3. An experiment was done to measure the work done by a 2.00-kg cart as its speed was increased. The data is shown in this chart.

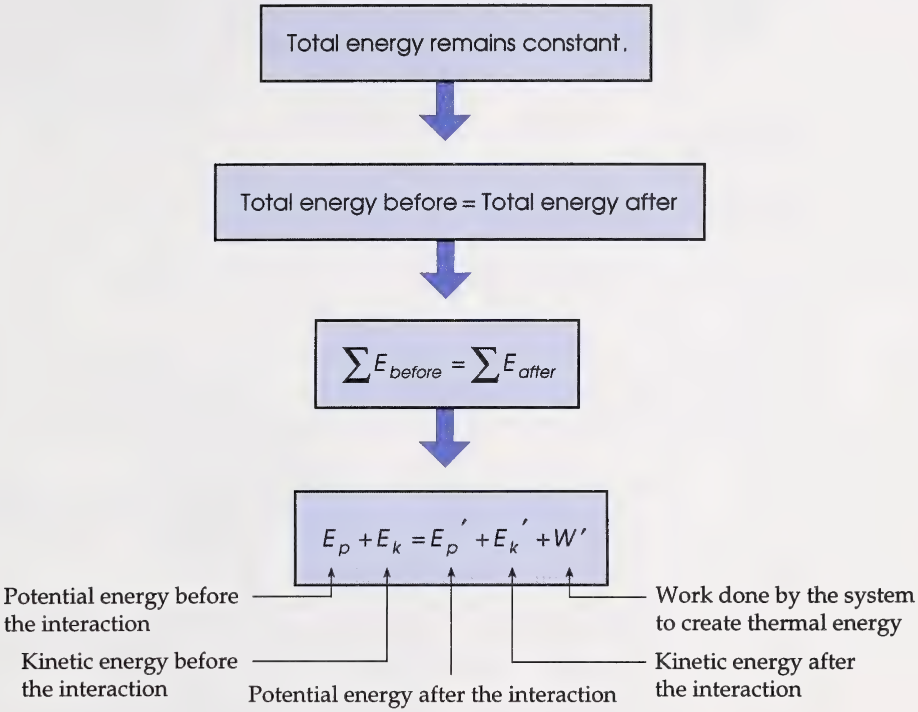
Work Done (J)	3.9	15.6	35.4	63.1	98.9
Speed (m/s)	2.0	4.0	6.0	8.0	10.0

   a. How could you produce a straight-line graph from this data with kinetic energy on the vertical axis? Complete the following flow chart to help answer this question.


Work done = Change in energy
The work is done by the kinetic energy of the cart.
$E_k = \frac{1}{2}mv^2$
Rearrange.
Use inspection.
$y = mx + b$

   b. What value would you expect for the slope of a kinetic energy-speed squared graph?

When you know a powerful technique, you can accomplish some amazing things. The technique you learned at the end of this section is based upon the law of conservation of energy. The following flow chart sums it all up.


Total energy remains constant.
Total energy before = Total energy after
$\sum E_{before} = \sum E_{after}$
$E_p + E_k = E_p{}' + E_k{}' + W'$
Potential energy before the interaction
Kinetic energy before the interaction
Potential energy after the interaction
Kinetic energy after the interaction
Work done by the system to create thermal energy

This technique can be applied to problems like the one that follows.

Example

A curling rock with a mass of 20.0 kg travels 14.0 m before coming to rest. If the force of friction on the rock is 2.0 N, at what speed was it thrown?

The following hints will help you think through the solution to this problem.

- The rock is on level ice, so gravitational potential energy is constant. Set the ice surface to be the level where gravitational potential energy is zero.
- The rock slows down. This means that the kinetic energy before is different than the kinetic energy after. You will need both of these terms.
- The rock does work against friction, so you need to consider the work done by the system to create thermal energy.

4. Use the hints to solve the curling rock problem using the recommended method.

Check your answers by turning to the Appendix, Section 2: Extra Help.

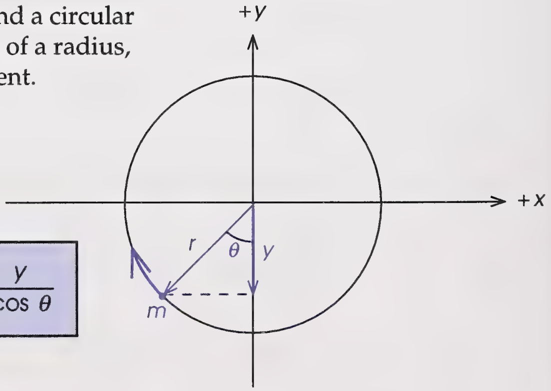
Enrichment

Do **one** of the following questions.

1. Derivation of $T = 2\pi\sqrt{\frac{m}{k}}$.

   The equation for the period of a mass vibrating on a spring actually has its origins in the link between circular motion and simple harmonic motion. You can begin to see the connection between these concepts with the following simple demonstration.

   - Begin to make a horizontal circle with your thumb. Try your best to move your thumb through the circle at a constant speed. Note that this circle is parallel to the floor.
   - When you look straight ahead at your thumb, you will see the circle edge-on. You can only see the horizontal motion of your thumb going back and forth. What does this horizontal motion remind you of? The horizontal motion of your thumb should remind you of the horizontal motion of a mass on a spring on a frictionless surface. In fact, a carefully designed experiment would verify that all simple harmonic motion is a one-dimensional component of circular motion. The following derivation shows how this idea can be used to derive $T = 2\pi\sqrt{\frac{m}{k}}$.
   - The motion of a mass, *m*, around a circular path can be described in terms of a radius, *r*. This radius has a *y*-component.



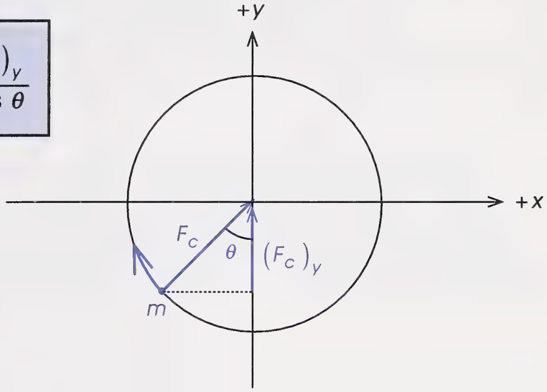
$$\boxed{y = r(\cos\theta)} \quad \text{or} \quad \boxed{r = \frac{y}{\cos\theta}}$$

- The mass experiences a centripetal force, F_c, which is directed to the centre of the circle. This force has a *y*-component $(F_c)_y$.

$$\boxed{(F_c)_y = F_c(\cos\theta)}$$

or

$$\boxed{F_c = \frac{(F_c)_y}{\cos\theta}}$$



$$\boxed{F_c = \frac{4\pi^2 mr}{T^2}}$$

Substitute.

$$\boxed{\left(\frac{(F_c)_y}{\cos\theta}\right) = \frac{4\pi^2 m}{T^2}\left(\frac{y}{\cos\theta}\right)}$$

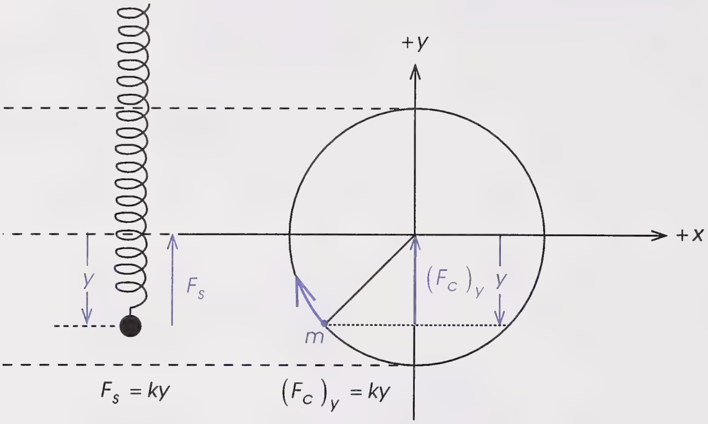
Simplify.

$$\boxed{(F_c)_y = \frac{4\pi^2 m}{T^2}y}$$

Since the mass and the period are a constant, $\frac{4\pi^2 m}{T^2}$ can be replaced by a constant, *k*.

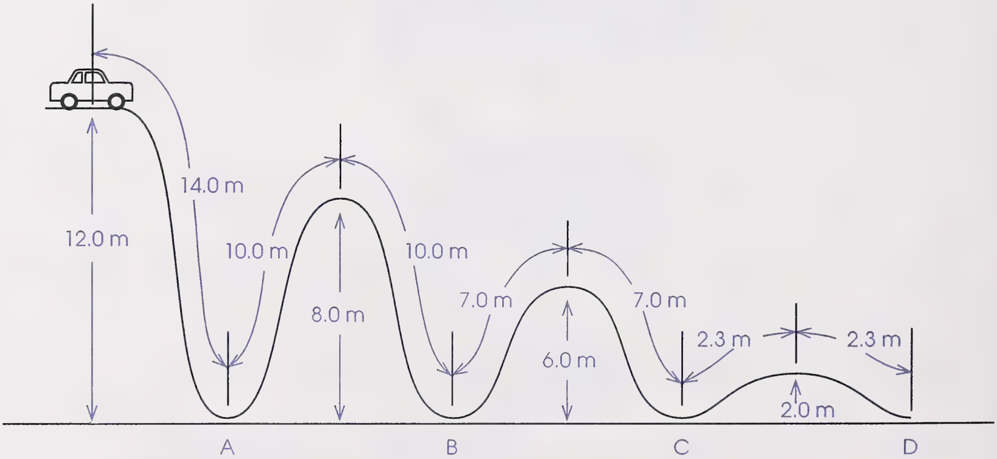
$$\boxed{(F_c)_y = ky}$$

The following diagram shows a mass vibrating horizontally back and forth on a frictionless surface beside another mass in circular motion. Both objects have the same period of vibration and would be seen to follow the same path when viewed edge-on. Since the y-components of the displacements are identical and synchronized, it follows that the y-components of the forces should also be identical. The proportionality constants, k, should be identical as well.



Complete the derivation to show that $T = 2\pi\sqrt{\frac{m}{k}}$.

2. Look at this ramp. If the car coasts from rest, at which spot will it end up? A constant friction force of 1100 N is acting. The mass of the car is 800.0 kg.



Check your answers by turning to the Appendix, Section 2: Enrichment.

Conclusion

In this section you demonstrated to yourself that energy can be conserved in a closed, isolated system. Since no exception has ever been found, it is known as the law of conservation of energy. This permits an approach to problem solving that is exceptionally effective and powerful. You will be able to use this idea throughout the remainder of the course.

Assignment Booklet

ASSIGNMENT

Turn to your Assignment Booklet and do the assignment for Section 2.

MODULE SUMMARY

The overview of this module promised to give you important preparation that would help you to be successful in Physics 30. As you work through the rest of the course, the things that you carry forward from this module will be called upon again and again. Some of these things are skills like graphical analysis and problem-solving techniques. Probably the most important thing that you will take through the rest of the course is the law of conservation of energy. This is considered to be the most important idea in all of physics, and you'll find that it plays a central role in understanding the topics that lie ahead.

Appendix

- Glossary
- Science Skills
- Suggested Answers
- Pull-out Page

Glossary

analysis: identifying trends, patterns, relationships, and accuracy in an experiment

closed system: a system in which matter is not allowed to enter or leave the system

empirical knowledge: knowledge gained from experiencing something; describes events

energy: the ability to do work or cause a disturbance in a system's surroundings

equilibrium position: the location where the net force acting on a system is zero

evaluating: determining the significance or worth of an experiment; identifying the limitations of the data

gravitational potential energy: the work done against gravity to change the position of an object

heat: the flow of thermal energy from a region of high temperature to a region of low temperature

hypothesis: theoretical knowledge on which a prediction is based

isolated system: a system in which external forces do not act, so energy is not allowed to enter or leave the system

joule: the SI unit of work and energy; the work done when a 1-N force is exerted over a 1-m displacement

kinetic energy: energy due to the motion of an object

mechanical energy: the sum of kinetic and potential energy

open system: a system in which matter is allowed to enter or leave the system

potential energy: energy due to the position or condition of an object, always associated with a force

power: the rate of doing work or the rate of using energy

prediction: a guess about how an experiment will turn out

problem: the specific question that an experiment is to answer

reference level: the location defined to have zero potential energy

science skills: problem-solving skills useful in science and in daily life

simple harmonic motion: the motion exhibited by any vibrating system in which a force restores the system to its equilibrium position; the force is proportional to the displacement but acts in the opposite direction

synthesizing: putting ideas together; constructing a whole from the parts

system: a defined collection of objects to be studied

temperature: a measure that indicates the average kinetic energy of an object's molecules

theoretical knowledge: knowledge gained by developing theories, models, and other constructs; explains why

thermal energy: the total energy (both potential and kinetic energy) of an object's molecules

thermodynamics: the study of heat transfer

unloaded position: the location of the lowest coil of a vertical spring when no mass is attached

watt: the SI unit of power, equal to 1 J of work per second

work: the product of force and displacement

work-energy theorem: one form of the law of conservation of energy; net work done on a system equals the change in its energy

Science Skills

A Framework for Scientific Problem-Solving Skills

A. Initiating and Planning

- Identify and clearly state the problem or issue to be investigated.
- Differentiate between relevant and irrelevant data or information.
- Assemble and record background information.
- Identify all variables and controls.
- Identify materials and apparatus required.
- Formulate questions, hypotheses, and/or predictions to guide research.
- Design and/or describe a plan for research or to solve the problem.
- Prepare required observation charts or diagrams.

B. Collecting and Recording

- Carry out and modify the procedure if necessary.
- Organize and correctly use apparatus and materials to collect reliable experimental data.
- Accurately observe, gather, and record information or data according to safety regulations (e.g., WHMIS) and environmental considerations.

C. Organizing and Communicating

- Organize and present data in a concise and effective form (themes, groups, tables, graphs, flow charts, and Venn diagrams).
- Communicate data more effectively, using mathematical and statistical calculations where necessary.
- Express measured and calculated quantities to the appropriate number of significant digits and use appropriate SI units for all quantities.

D. Analysing

- Analyse data and information for trends, patterns, relationships, reliability, and accuracy.
- Identify and discuss sources of error and their effect on results.
- Identify assumptions, attributes, bias, claims, or reasons.

- Identify main ideas.

E. Connecting, Synthesizing, and Integrating

- Predict from data or information.
- Formulate further testable hypotheses supported by the knowledge and understanding generated.
- Identify alternatives for consideration.
- Propose and explain interpretations or conclusions.
- Develop theoretical explanations.
- Relate the data to laws, principles, models, or theories identified in background information.
- Answer the problem investigated.
- Summarize and communicate findings.
- Decide on a course of action.

F. Evaluating the Process or Outcomes

- Establish criteria to judge data or information.
- Consider consequences and perspectives.
- Identify limitation of the data, information, interpretations, or conclusions as a result of the experimental/research/project/design processes or methods used.
- Suggest alternatives and consider improvements to experimental technique and design.
- Evaluate and assess ideas, information, and alternatives.

Criteria for Assessing Scientific Problem-Solving Skills

A. Initiating and Planning

Level 1	Level 2	Level 3	Level 4	Level 5
• Proposes a simple problem statement when initiated to do so	• Proposes a simple problem statement	• Proposes a problem to be investigated	• Clearly states the purposes and problem to be investigated	• Performs at a level beyond level 4
• Background information must be supplied	• Background information is supplied from teacher or student's own experience	• Background supplied by teacher, reference material, or student's own experience	• Prepares the necessary background information from references, research, discussion, and/or past experience	• Characteristic of work done at college or university level
• Identifies those things that change and those that stay the same	• Identifies variables and controls	• Identifies controls, manipulated variables, and responding variables	• Identifies the controls and variables	
• Guesses about the outcomes	• Makes 'educated' guesses	• Makes a prediction and/or suggests a simple hypothesis	• Forms an appropriate hypothesis and prediction • Designs an investigation	
• Identifies simple materials and equipment to be used	• Identifies materials and equipment to be used • Is able to assemble simple apparatus	• Identifies the materials and equipment to be used • Assembles simple apparatus	• Identifies and names the materials and equipment to be used • Assembles and designs or modifies simple apparatus	
• Follows directions as provided	• Follows directions as provided • Is able to write simple procedural statements	• Develops and organizes a simple written procedure	• Designs and writes descriptions of procedures that are clear and detailed	
	• Prepares observation charts, tables, and diagrams as directed by teacher	• Prepares observation charts, tables, diagrams, graphs • Performs calculations as outlined by teacher	• Prepares observation charts, diagrams, and graphs • Performs necessary calculations	

B. Collecting and Recording

Level 1	Level 2	Level 3	Level 4	Level 5
• Follows a simple procedure	• Follows a simple procedure	• Follows a given procedure and is able to suggest modifications when asked to do so	• Follows a given procedure and modifies the procedure when necessary	• Performs at a level beyond level 4
• Correctly uses apparatus and materials as directed by teacher	• Correctly uses apparatus and materials with little teacher assistance	• Correctly uses apparatus and materials with infrequent modification	• Consistently uses standard apparatus and materials correctly	• Characteristic of work done at college or university level
• Collects data using concrete, tangible objects	• Collects tangible objects • Carries out simple measurements	• Accurately collects data	• Accurately collects relevant data	
• Records data in sentence form or in simple charts that have been constructed	• Records data in numerical and non-numerical form • Is able to use and construct simple charts	• Records relevant data including the correct units with respect to measured data	• Records relevant data using the appropriate units	
• Is aware of safety and environmental concerns • Follows stated safety procedures	• Is aware of safety and environmental concerns • Follows stated safety procedures	• Shows appropriate safety and environmental concerns in the use, care, and maintenance of materials and apparatus	• Demonstrates appropriate standards of safety	
		• Is able to locate appropriate safety regulations • Actively participates in teacher-directed discussion of safety and environmental issues	• Is able to suggest modifications to procedures to minimize environmental damage	

C. Organizing and Communicating

Level 1	Level 2	Level 3	Level 4	Level 5
• Organizes data in sets of concrete objects	• Organizes data in sets of objects	• Organizes data in the form of sets, themes, and/or tables	• Organizes data accurately	• Performs at a level beyond level 4
	• Provides a basis for the organization of data sets • Constructs simple graphs to represent the data	• Provides a basis for and suggests alternatives for the organization of data • Is able to construct graphs and/or tables to represent the data	• Is able to represent data using appropriate graphs and tables	• Characteristic of work done at college or university level
	• Performs basic mathematical calculations	• Performs basic mathematical calculations	• Performs relevant and required mathematical calculations	
	• Identifies, with teacher assistance, errors and inaccuracies	• Identifies errors and discrepancies in data • Takes part in teacher-directed discussion of scientific inaccuracies	• Expresses measured and calculated quantities to correct degree of precision	

D. Analysing

Level 1	Level 2	Level 3	Level 4	Level 5
• Correctly identifies patterns within the data	• Assesses patterns and trends that are conceptually presented by the data	• Assesses patterns, trends, and simple relationships	• Assesses patterns, trends, and relationships resulting from collected and manipulated data	• Performs at a level beyond level 4
• Identifies, with teacher assistance, relationships	• Identifies simple cause and effect relationships	• Identifies cause and effect relationships	• Identifies the sources of error in data collection and manipulation	• Characteristic of work done at college or university level
	• Identifies, with teacher assistance, the sources of error in data collection and manipulation	• Identifies the sources of error in data collection and manipulation	• Expresses accuracy qualitatively and/or quantitatively (percent difference), where applicable • Identifies the assumptions relating to measurement and/or analysis	
	• Identifies, with teacher assistance, the effect of errors on results	• Suggests amendments to procedures and/or data manipulation in order to rectify results	• Determines the reliability of the data	

E. Connecting, Synthesizing, and Integrating

Level 1	Level 2	Level 3	Level 4	Level 5
• Provides a simple but not necessarily appropriate answer to the problem investigated based on results obtained	• Provides a simple answer that is appropriate for the problem investigated and results obtained	• Provides an appropriate answer to the problem investigated based on results obtained	• Provides a qualified answer to the problem investigated	• Performs at a level beyond level 4
	• Attempts to relate results to knowledge that is not specifically related to scientific theories or laws	• Relates results, with teacher assistance, to applicable theories and/or laws	• Relates the data to laws, principles, models, or theories identified in background information and/or in broader context	• Characteristic of work done at college or university level
			• Proposes and explains interpretations or conclusions • Develops theoretical explanations	

F. Evaluating the Process or Outcomes

Level 1	Level 2	Level 3	Level 4	Level 5
• Attempts to explain results to the problem investigated	• Attempts to explain results to the problem investigated	• Is able to explain the results obtained in light of the problem being investigated	• Evaluates the prediction and concepts	• Restricts, revises, or replaces an unacceptable scientific concept
	• Attempts to draw conclusions where applicable and when prompted	• Draws conclusions and attempts to explain them	• Draws conclusions and attempts to explain them	• Establishes criteria to judge the design, prediction, and concepts
		• Discusses the limitations of the data collected, interpretations, and/or conclusions	• Identifies limitations of the data and information, interpretations, or conclusions, as a result of the design of the experiment, research, or project	• Considers consequences and perspectives • Evaluates assumptions and effects of bias
		• Discusses, when prompted, the validity of results • Discusses, when prompted, alternatives and/or improvements to the experimental design	• Suggests alternatives and considers improvements to experimental technique and design	• Evaluates the total investigation in terms of reliability and validity

Suggested Answers

Section 1: Activity 1

1. The muscle fibres in your arm contract. The work is done inside your arm.

2. Textbook question 2:

$W = 2.20 \times 10^5 \text{ J}$
$d = 8.00 \text{ m}$
$F = ?$

$$\begin{aligned} W &= Fd \\ F &= \frac{W}{d} \\ &= \frac{2.20 \times 10^5 \text{ J}}{8.00 \text{ m}} \\ &= 2.75 \times 10^4 \text{ N} \end{aligned}$$

Textbook question 3:

$F = 551 \text{ N}$
$d = 161 \text{ km}$
$\quad = 161\,000 \text{ m}$
$W = ?$

$$\begin{aligned} W &= Fd \\ &= (551 \text{ N})(161\,000 \text{ m}) \\ &= 8.87 \times 10^7 \text{ J} \end{aligned}$$

or

$$\begin{aligned} W &= Fd \\ &= (551 \text{ N})(161 \text{ km}) \\ &= 8.87 \times 10^4 \text{ kJ} \end{aligned}$$

Textbook question 10:

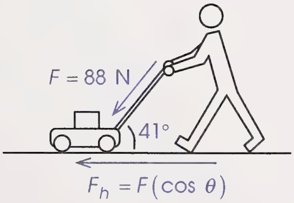
$F = 15.0 \text{ N}$
$d = 251 \text{ m}$
$t = 30.0 \text{ s}$
$P = ?$

$$\begin{aligned} P &= \frac{W}{t} \\ &= \frac{Fd}{t} \\ &= \frac{(15.0 \text{ N})(251 \text{ m})}{30.0 \text{ s}} \\ &= 126 \text{ W} \end{aligned}$$

3. Textbook question 7:

$F = 88.0 \text{ N}$
$F_h = ?$
$\theta = 41°$
$d = 1.2 \text{ km} = 1200 \text{ m}$
$W = ?$

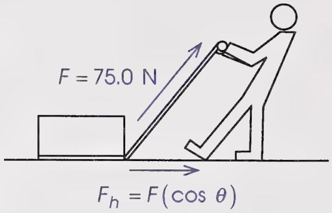
$$\begin{aligned} W &= Fd(\cos \theta) \\ &= (88.0 \text{ N})(1200 \text{ m})(\cos 41°) \\ &= 8.0 \times 10^4 \text{ J} \end{aligned}$$



Textbook question 8:

$m = 17.0\ \text{kg}$
$d = 20.0\ \text{m}$
$W = 1210\ \text{J}$
$F = 75.0\ \text{N}$
$\theta = ?$

$$\begin{aligned} W &= Fd(\cos\,\theta) \\ \cos\,\theta &= \frac{W}{Fd} \\ &= \frac{1210\ \text{J}}{(75.0\ \text{N})(20.0\ \text{m})} \\ &= 0.80\overline{6} \\ \theta &= 36.2^\circ,\ \text{from horizontal} \end{aligned}$$



4. Textbook question 1:

$m = 84.0\ \text{kg}$
$d = 120\ \text{cm} = 1.20\ \text{m}$
$W = ?$

$$\begin{aligned} W = Fd &= mgd \\ &= (84.0\ \text{kg})(9.81\ \text{m/s}^2)(1.20\ \text{m}) \\ &= 989\ \text{J} \end{aligned}$$

Textbook question 9:

$m = 1.1 \times 10^3\ \text{kg}$
$d = 40.0\ \text{m}$
$t = 12.5\ \text{s}$
$P = ?$

$$\begin{aligned} P &= \frac{W}{t} = \frac{mgd}{t} \\ &= \frac{(1.1 \times 10^3\ \text{kg})(9.81\ \text{m/s}^2)(40.0\ \text{m})}{12.5\ \text{s}} \\ &= 3.5 \times 10^4\ \text{W or 35 kW} \end{aligned}$$

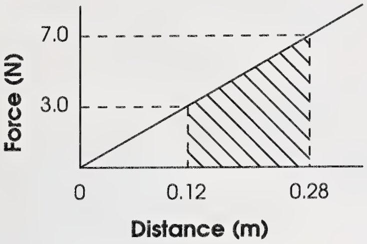
Textbook question 12:

$m = 35\ \text{kg}\ (35\ \text{L of water} = 35\ \text{kg})$
$t = 60\ \text{s}$
$d = 110\ \text{m}$
$P = ?$

$$\begin{aligned} P &= \frac{mgd}{t} \\ &= \frac{(35\ \text{kg})(9.81\ \text{m/s}^2)(110\ \text{m})}{60\ \text{s}} \\ &= 6.3 \times 10^2\ \text{W or 0.63 kW} \end{aligned}$$

5. Textbook question 5:

The area is a trapezoidal shape.

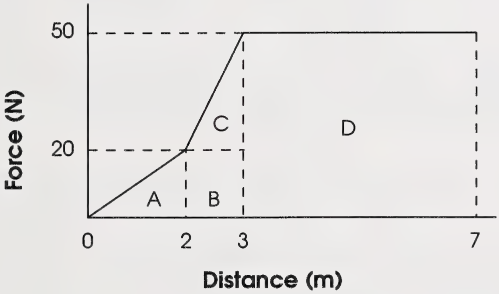


$$\begin{aligned} \text{area} &= \frac{1}{2}a\left(b_1 + b_2\right) \\ &= \frac{1}{2}(0.16\ \text{m})(3.0\ \text{N} + 7.0\ \text{N}) \\ &= 0.80\ \text{J} \end{aligned}$$

You may use any other formula that works to find the area. For example, you could subtract two triangles.

Textbook question 20.a.:

a. The area is a complicated shape made up of lots of simple shapes.



$$\begin{aligned} \text{area} &= \text{A} + \text{B} + \text{C} + \text{D} \\ &= \frac{1}{2}ab + \ell w + \frac{1}{2}ab + \ell w \\ &= \frac{1}{2}(2\ \text{m})(20\ \text{N}) + (1\ \text{m})(20\ \text{N}) + \frac{1}{2}(1\ \text{m})(30\ \text{N}) + (4\ \text{m})(50\ \text{N}) \\ &= 20\ \text{J} + 20\ \text{J} + 15\ \text{J} + 200\ \text{J} \\ &= 255\ \text{J} \end{aligned}$$

Textbook question 20.b.:

$$\begin{aligned} P &= \frac{W}{t} \\ &= \frac{255\ \text{J}}{2.0\ \text{s}} \\ &= 1.3 \times 10^2\ \text{W} \end{aligned}$$

6. The slope can be calculated between any two points on the line. You should use as much of the line as you can. The sample calculation uses the following points: $(0, 0)$, $(150, 50)$.

$$\begin{aligned} \text{slope} &= \frac{\text{rise}}{\text{run}} \\ &= \frac{150\ \text{J} - 0\ \text{J}}{50\ \text{s} - 0\ \text{s}} \\ &= 3.0\ \text{W} \end{aligned}$$

7. The parts of the textbook with information on kinetic energy are pages 218 to 222. This can be found by referring to the index or table of contents in the textbook.

8. You could check your understanding by doing some of the Practice Problems on pages 221 and 222 of your textbook. The answers to these problems could be checked on pages 672 and 673 of your textbook.

9. The equations for work and power from the Physics 30 data sheets are $W = Fd$, $W = Fd(\cos\,\theta)$, and $P = \frac{W}{t}$. These same equations are used in the Appendix of this module. You should use the equations as they are presented in the Physics 30 data sheets and in the Appendix of each module.

10. The value for the acceleration due to gravity in the Physics 30 data sheets is $9.81\ \text{m/s}^2$. The same value is used in the Appendix of this module, but the textbook uses $9.80\ \text{m/s}^2$. You should use $9.81\ \text{m/s}^2$ to be consistent with the Physics 30 data sheets and the Appendix of each module.

11. The goal of a Physics 30 student is to **understand** the main physics concepts and to see how these concepts **apply** to other ideas in the fields of science, technology, and society. When you write down the basic equations and show how they interconnect, you are communicating the main physics concepts. The numerical answer is really only a small part of the answer. In fact, on the diploma exam, the correct number usually only counts for half a mark on a four-mark question. Since the majority of the marks given on a diploma exam are awarded for a solid understanding of the main concepts and the application of these concepts, you should be practising the communication of these things in your work.

12. Just like riding a bike, skating, and swimming, you learn the skills of problem solving by doing, not by watching. The best approach is to work out the solution to a problem **without looking at the Appendix answers until you have completely finished**. If you get into the habit of always looking for hints before trying it yourself, you may find it very difficult to work without any hints. This could make assignments and exams very frustrating.

13. $m = 9.0\ \text{kg}$
$d = 6.97\ \text{m}$
$g = 9.81\ \text{m/s}^2$
$W = ?$

The data is listed as the first step. The value of *g* is $9.81\ \text{m/s}^2$, which is consistent with the data sheets.

$W = Fd$

The equation for work from the data sheets

$= mgd$

The equation $F = mg$ is substituted.

$= (9.0\ \text{kg})(9.81\ \text{m/s}^2)(6.97\ \text{m})$

The data and units are substituted.

$= 615.38\ \text{J}$

This step is not necessary, but shows the answer prior to rounding.

$= 6.2 \times 10^2\ \text{J}$

The final answer shows the answer with the correct units and the correct number of significant digits.

14. The answers to this question will vary depending on the learning style that you prefer. However, your answer should include practising the strategies and techniques shown in the activities and the Appendix of each module. It is important that you develop an approach that lets you be an active learner by doing the problems, rather than passively reading the Appendix without trying the questions yourself.

Section 1: Activity 2

1. The answers to these questions can be found on page 672 of your textbook.

2. The answers to these questions can be found on page 673 of your textbook.

3. Gravitational potential energy is defined as the work done against gravity to change the position of an object. Since work must be done on an object, it must be forced through a displacement that starts at some initial position. The starting position for the work to be done is the reference level. It is important for the reference level not to change. If the reference level did change, an object could have different values for gravitational potential energy even though it was in the same position.

4. Textbook question 3.a.:

$F = 30.0\ \text{N}$
$m = 1.5\ \text{kg}$
$d = 2.8\ \text{m}$
$W = ?$
$\Delta E_k = ?$
$\vec{v}_f = ?$

$$W = Fd$$
$$= (30.0\ \text{N})(2.8\ \text{m})$$
$$= 84\ \text{J}$$

Textbook question 3.b.:

84 J of work adds 84 J of E_k to the cart.

Textbook question 3.c.:

$$\Delta E_k = \frac{1}{2}mv^2$$
$$v = \sqrt{\frac{2\,\Delta E_k}{m}}$$
$$= \sqrt{\frac{2(84\ \text{J})}{1.5\ \text{kg}}}$$

$\vec{v} = 11\ \text{m/s}$ in the direction of the force

Textbook question 7:

ΔE_p is equal to the work done going up, so the following calculation is appropriate.

$m = 90.0\ \text{kg}$

$h = 8 \times 40\ \text{cm} = 3.2\ \text{m}$

$\Delta E_p = ?$

$$\begin{aligned}\Delta E_p &= Fd \\ &= mgh \\ &= (90.0\ \text{kg})(9.81\ \text{m/s}^2)(3.20\ \text{m}) \\ &= 2.8 \times 10^3\ \text{J or } 2.8\ \text{kJ}\end{aligned}$$

5. Textbook question 9:

$m = 0.18\ \text{kg}$

$F = 2.8\ \text{N}$

$d = 15\ \text{cm} = 0.15\ \text{m}$

$h = ?$

$$\begin{aligned}W &= Fd \\ &= (2.8\ \text{N})(0.15\ \text{m}) \\ &= 0.42\ \text{J}\ (\text{This is kinetic energy.})\end{aligned}$$

E_k changes to E_p at the top.

$$\begin{aligned}E_p &= mgh \\ h &= \frac{E_p}{mg} \\ &= \frac{0.42\ \text{J}}{(0.18\ \text{kg})(9.81\ \text{m/s}^2)} \\ &= 0.24\ \text{m or } 24\ \text{cm}\end{aligned}$$

Textbook question 11.a.:

$m = 15.0\ \text{kg}$

$v = 12.5\ \text{m/s}$

$E_k = ?$

$$\begin{aligned}E_k &= \frac{1}{2}mv^2 \\ &= \frac{1}{2}(15.0\ \text{kg})(12.5\ \text{m/s})^2 \\ &= 1.17 \times 10^3\ \text{J}\end{aligned}$$

Textbook question 11.b.:

The plane loses 20.4 m of height, so use this calculation.

$$\begin{aligned}\Delta E_p &= mgh \\ &= (15.0\ \text{kg})(9.81\ \text{m/s}^2)(20.4\ \text{m}) \\ &= 3.00 \times 10^3\ \text{J}\end{aligned}$$

Textbook question 11.c.:

Since E_{total} is constant, a loss of E_p is equal to a gain of E_k.

$\Delta E_k = 3.00 \times 10^3\ \text{J}$

Textbook question 11.d.:

$$\begin{aligned}E_{k(new)} &= E_{k(old)} + \Delta E_k \\ &= 1.17 \times 10^3\ \text{J} + 3.00 \times 10^3\ \text{J} \\ &= 4.17 \times 10^3\ \text{J}\end{aligned}$$

Textbook question 11.e.:

$$\begin{aligned}E_k &= \frac{1}{2}mv^2 \\ v &= \sqrt{\frac{2E_k}{m}} \\ &= \sqrt{\frac{2(4.17 \times 10^3\ \text{J})}{15.0\ \text{kg}}}\end{aligned}$$

$\vec{v} = 23.6\ \text{m/s}$ in the direction the plane was originally going

6. $P = 25 \text{ W}$

$t = 30 \text{ s}$

$m = 2.0 \text{ kg}$

$h = ?$

$$\begin{array}{ccc} P = \dfrac{W}{t} & & W = \Delta E_p \\ Pt = W & & W = mgh \\ \downarrow & & \downarrow \\ Pt & = & mgh \end{array}$$

$$\begin{aligned} Pt &= mgh \\ h &= \frac{Pt}{mg} \\ &= \frac{(25 \text{ W})(30 \text{ s})}{(2.0 \text{ kg})(9.81 \text{ m/s}^2)} \\ &= 38 \text{ m} \end{aligned}$$

7. $m = 70.0 \text{ kg}$

$W = 1.40 \text{ kJ} = 1400 \text{ J}$

$h = ?$

Work goes into elastic energy and elastic energy converts to potential energy, so the following calculation is appropriate.

$$\begin{aligned} W &= mgh \\ h &= \frac{W}{mg} \\ &= \frac{1400 \text{ J}}{(70.0 \text{ kg})(9.81 \text{ m/s}^2)} \\ &= 2.04 \text{ m} \end{aligned}$$

8. $m = 150 \text{ g} = 0.150 \text{ kg}$

$F = 100 \text{ N}$

$d = 75.0 \text{ cm} = 0.750 \text{ m}$

$v = ?$

$h = ?$

a. Elastic energy from the work done converts to kinetic energy.

$$\begin{aligned} Fd &= \frac{1}{2}mv^2 \\ v &= \sqrt{\frac{2Fd}{m}} \\ &= \sqrt{\frac{2(100 \text{ N})(0.750 \text{ m})}{0.150 \text{ kg}}} \\ &= 31.6 \text{ m/s} \end{aligned}$$

b. Kinetic energy converts to potential energy.

$$\begin{aligned} \frac{1}{2}\overset{1}{\cancel{m}}v^2 &= \overset{1}{\cancel{m}}gh \\ h &= \frac{v^2}{2g} \\ &= \frac{(31.6 \text{ m/s})^2}{2(9.81 \text{ m/s}^2)} \\ &= 51.0 \text{ m} \end{aligned}$$

9. $h = 1100 \text{ m}$

$v_i = 0 \text{ m/s}$

$v_f = ?$

Potential energy at the top converts to kinetic energy at the bottom.

$$\begin{aligned} \overset{1}{\cancel{m}}gh &= \frac{1}{2}\overset{1}{\cancel{m}}v^2 \\ v &= \sqrt{2gh} \\ &= \sqrt{2(9.81 \text{ m/s}^2)(1100 \text{ m})} \\ &= 147 \text{ m/s} \\ &= 529 \text{ km/h} \end{aligned}$$

Is this realistic? No, it is not realistic because air resistance is a big factor here.

Section 1: Activity 3

1. a. This part of the story best shows the skill of **initiating and planning** because in this step Ahmed states the problem.

   b. This part of the story best shows the skill of **initiating and planning** because in this step Ahmed is differentiating between relevant and irrelevant information.

   c. This part of the story best shows the skill of **initiating and planning** because in this step Ahmed is devising a plan to solve the problem.

   d. This part of the story best shows the skill of **collecting and recording** because in this step Ahmed is carrying out the procedure.

   e. This part of the story best shows the skill of **collecting and recording** because in this step Ahmed is accurately observing, gathering, and recording information.

   f. This part of the story best shows the skill of **organizing and communicating** because in this step Ahmed is organizing and presenting the data in a more effective form.

   g. This part of the story best shows the skill of **analysing** because in this step Ahmed is identifying attributes within the data.

   h. This part of the story best shows the skill of **connecting, synthesizing, and integrating** because in this step Ahmed is identifying alternatives for consideration.

   i. This part of the story best shows the skill of **connecting, synthesizing, and integrating** because in this step Ahmed is answering the problem to be investigated and deciding upon a course of action.

   j. This part of the story best shows the skill of **evaluating the process or outcomes** because in this step Ahmed is evaluating and assessing ideas, information, and alternatives.

Investigation: Projectile Marbles

The following is a sample of the completed data chart for this investigation. Your data values may vary from what is given here, but the trends in the data should be similar. The table height used for this sample data chart is 0.865 m.

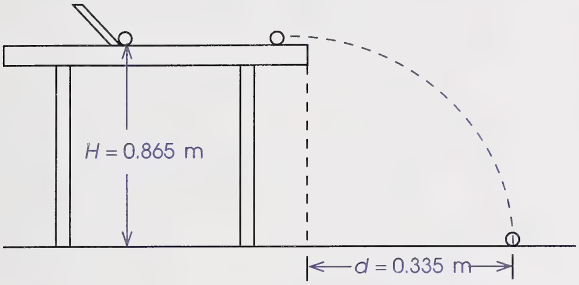
Trial	Ramp Height (*h*) (m)	Horizontal Distance Travelled (*d*) (m)
1	0.060	0.335
2	0.080	0.402
3	0.100	0.448
4	0.120	0.496
5	0.140	0.536
6	0.160	0.583

2. As the height of the ramp increases, the horizontal distance travelled by the marble increases.

Section 1: Activity 4

The sample data shown in the following chart is the same as that used in the previous investigation in Activity 3. The table height used for this sample data chart is 0.865 m. Your values may differ from the sample values due to differences in your particular setup. The following sample calculations show how the first two values for horizontal speed were calculated from the height of the table and the other sample values.

Trial 1:



Use the equation for vertical motion to obtain a value for *t*.

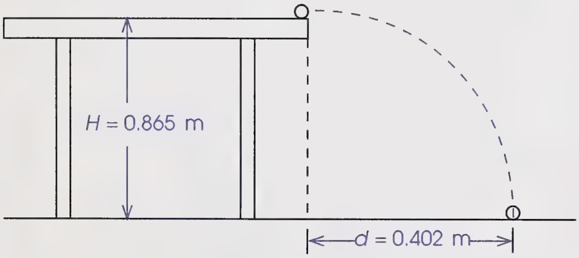
$$H = \frac{1}{2}gt^2$$
$$t^2 = \frac{2H}{g}$$
$$t = \sqrt{\frac{2H}{g}}$$
$$= \sqrt{\frac{2(0.865\ \text{m})}{9.81\ \text{m/s}^2}}$$
$$= 0.42\ \text{s}$$

You can now use the formula for horizontal motion to find the horizontal speed.

$$v = \frac{d}{t}$$
$$= \frac{0.335\ \text{m}}{0.42\ \text{s}}$$
$$= 0.80\ \text{m/s}$$

Trial 2:

Since the height of the table does not change, the time does not change $(t = 0.42\ \text{s})$. The only difference will be the horizontal distance travelled.

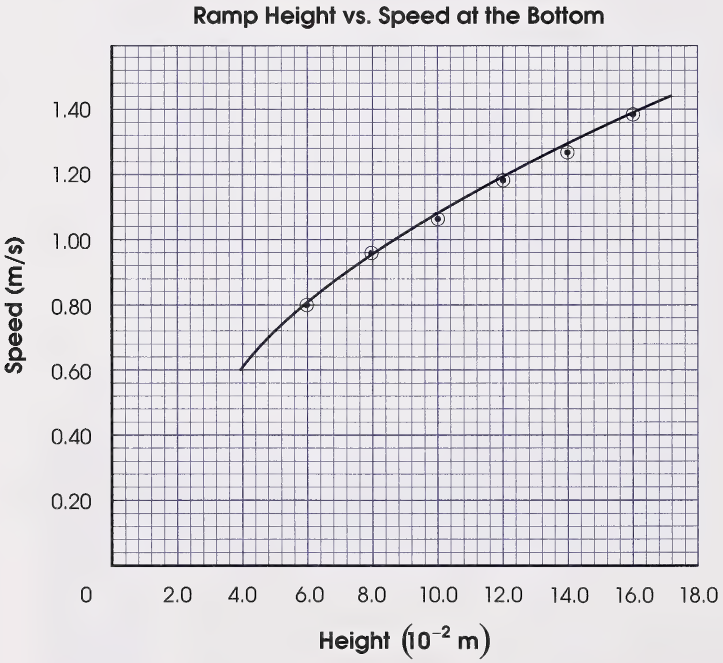


$$v = \frac{d}{t}$$
$$= \frac{0.402\ \text{m}}{0.42\ \text{s}}$$
$$= 0.96\ \text{m/s}$$

Table 1

Trial	Ramp Height (*h*) (m)	Horizontal Distance (*d*) (m)	Horizontal Speed (*v*) (m/s)
1	0.060	0.335	0.80
2	0.080	0.402	0.96
3	0.100	0.448	1.07
4	0.120	0.496	1.18
5	0.140	0.536	1.28
6	0.160	0.583	1.39

1. This graph is drawn using the sample data from the data chart. Your plotted line will have different points, but the best-fit line should show the same trend as shown here.



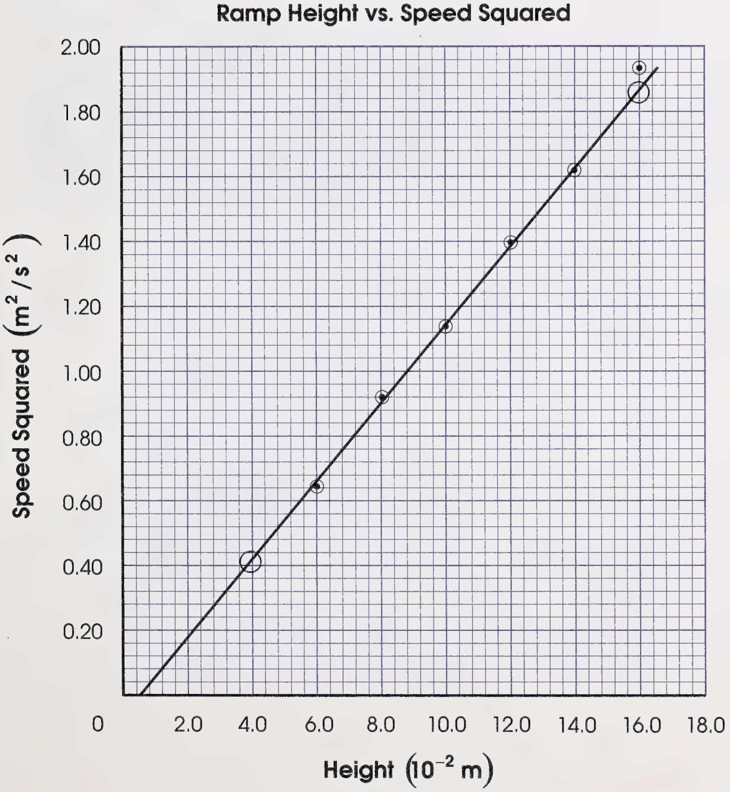
Drawing the best-fit line for this data requires some thinking on your part. At first it might seem like the data points form a straight line, but that would give a *y*-intercept of 0.40 m/s, which doesn't make sense. After all, should a ramp height of zero have a corresponding marble speed of 0.40 m/s? Clearly, if the ramp height is zero, the ramp is perfectly level and the marble should have a corresponding speed of zero. The best-fit line should be a curve that eventually goes through the origin.

This data chart contains sample data. Your data may differ, but the data trend should be similar.

Table 2

Trial	Ramp Height (h) (m)	Horizontal Speed (v) (m/s)	Horizontal Speed Squared (v^2) (m^2/s^2)
1	0.060	0.80	0.64
2	0.080	0.96	0.92
3	0.100	1.07	1.14
4	0.120	1.18	1.40
5	0.140	1.28	1.63
6	0.160	1.39	1.93

2.



This is a straight line with some scatter in the points. The origin is a theoretical point too, but this line does **not** point to it and as such, the origin is not an empirical point.

3. Using the two circled points in the sample graph in question 2, $\left(4.0\times10^{-2}\ \text{m},\ 0.42\ \text{m}^2/\text{s}^2\right)$ and $\left(16.0\times10^{-2}\ \text{m},\ 1.88\ \text{m}^2/\text{s}^2\right)$, the slope is calculated as shown.

$$\begin{aligned}\text{slope} &= \frac{\text{rise}}{\text{run}}\\ &= \frac{\left(1.88\ \text{m}^2/\text{s}^2\right)-\left(0.42\ \text{m}^2/\text{s}^2\right)}{\left(16.0\times10^{-2}\ \text{m}\right)-\left(4.0\times10^{-2}\ \text{m}\right)}\\ &= \frac{1.46\ \text{m}^2/\text{s}^2}{12.0\times10^{-2}\ \text{m}}\\ &= 12.2\ \text{m}/\text{s}^2\end{aligned}$$

4. $2g = 12.2\ \text{m}/\text{s}^2$

   $g = 6.1\ \text{m}/\text{s}^2$

5. Parts of Nicole's prediction held up and parts did not. The relationship is linear and although the line misses the origin, it doesn't miss by much. The slope, however, is not close to the predicted value. A tough judge would falsify the prediction.

6. The experimental design was probably adequate to answer the question. The relationship between height and speed is that height is proportional to speed squared. This is consistent with potential and kinetic energy, since height relates to potential energy and speed squared relates to kinetic energy.

7. Measured values are probably within 3% of being correct. This accounts for accepting a 10% to 15% error in this experiment. Does friction come into play? Is there another retarding influence in your ramp? Does the marble leave the table perfectly horizontally? Did you let go of the marble in a consistent manner? These questions indicate other sources of error.

8. Possible improvements to your procedure might include making a release mechanism for the marble or putting a carbon paper on the ground to mark the landing site. Reading up on what else might be happening here would also help to improve the design.

9. a.

Level of Initiating and Planning	
Ravi	**Dietmar**
Level 2 Ravi has a unique plan. However, when his initial plan fails, he does not have a method that gives him an answer to the nearest centimetre. A level 3 response would have involved a follow-up plan once the first one failed. Perhaps he could have looked for another blueprint. A level 4 response would have all that a level 3 response does, but would include a very detailed list of contact people and confirmation from other sources that his expert advice is correct. Level 4 responses involve the student actively preparing, researching, and anticipating all the alternatives.	Level 3 Dietmar's plan outlines a clear method that produces a result in centimetres. A level 4 response would have considered some variables that Dietmar forgot about. Are all the blocks exactly the same size? Has the amount of mortar between the blocks been considered? Is the amount of mortar between the blocks consistent? A level 4 response would have included a detailed write-up that would account for all these other things.

b.

Level of Collecting and Reporting	
Ravi	**Dietmar**
Level 2 Ravi followed a simple procedure and recorded his answer. A level 3 response would have involved modifications to his procedure so that his answer was expressed to the correct units. A level 4 response would have involved collecting data from many sources. A level 4 response would show all of the height measurements on a clearly labelled chart.	Level 2 Dietmar followed his procedure and carried out simple measurements. A level 3 response would have been more accurate, accounting for the thickness of the mortar. This measurement would have been neatly recorded with the others. A level 4 response would have involved taking the measurements of many bricks and sections of mortar. All of these values would be displayed on a clearly labelled chart with a value for average block height and average mortar thickness.

10. The answer to this problem may be best answered with another question. Who are you working for when you do your work in this course? You are working for yourself. It's your future that will depend on leaving high school with the skills that will help to make you successful. When you answer a question in an Assignment Booklet, it is worthwhile to ask yourself, "How did I do?" because this causes you to assess where you need to improve your skills. The real benefit to you is that you will come to know yourself better and you will begin to take personal responsibility for your life-long learning.

11. a. As each assignment is returned, record your assessment and the teacher's assessment under the appropriate columns on the spreadsheet.

    b. The whole point of keeping track of all the assessments in one place is to promote growth in your abilities. The sheet will help you to keep track of improvements and areas requiring further attention.

    c. The spreadsheet is in the Module 9 Assignment Booklet to provide a little extra incentive to record the assessments. You will receive ten marks on your last assignment for filling in this spreadsheet accurately and completely.

Section 1: Follow-up Activities

Extra Help

1. a. Work is done on a person's body to climb stairs and increase potential energy. The person has kinetic energy at the moment because they are moving.

   b. The person's gravitational potential energy is now given by $E_p = mgh$ at the top. The person also has kinetic energy because they are moving.

   c. The person flexes the diving board, giving it elastic potential energy.

   d. The board converts elastic energy into the person's kinetic energy and gravitational potential energy.

   e. Kinetic energy totally converts to potential energy at the top of the dive. The potential energy then converts to kinetic energy which reaches a maximum at the pool's surface.

   f. Kinetic energy converts to sound, heat, and kinetic energy of water (waves).

   g. The water's wave energy dissipates as heat.

2. $m = 1.00 \text{ kg}$
   $F = 150 \text{ N}$
   $d = 2.80 \text{ m}$
   $v = ?$
   $h = ?$

$$\begin{aligned} W &= Fd \\ &= (150 \text{ N})(2.80 \text{ m}) \\ &= 420 \text{ J} \end{aligned}$$

This means 420 J of kinetic energy.

$$\begin{aligned} E_k &= \frac{1}{2}mv^2 \\ v &= \sqrt{\frac{2E_k}{m}} \\ &= \sqrt{\frac{2(420 \text{ J})}{1.00 \text{ kg}}} \\ &= 29.0 \text{ m/s} \end{aligned}$$

420 J of kinetic energy means 420 J of potential energy.

$$
\begin{aligned}
E_p &= mgh \\
h &= \frac{E_p}{mg} \\
&= \frac{420\ \text{J}}{(1.00\ \text{kg})(9.81\ \text{m/s}^2)} \\
&= 42.8\ \text{m}
\end{aligned}
$$

3. a. A prediction has been made (from some hypothesis) and is the idea behind a problem statement.

   b. An overview (brief description) for an experiment has been thought up to answer a problem. A procedure will be written from it.

   c. The evaluation of the design has suggested an improved procedure which will be done next.

   d. The evaluation has suggested a new problem for which a new experiment will be designed.

Enrichment

1. Your research may have discovered the following things.

   - 1750: Joseph Black proposes the caloric theory which states that heat is a fluid that flows from hot to cold and which explains heating, cooling, expansion, and heating by friction.
   - 1800: Lavoisier, LaPlace, and Locke contribute the idea that heat is the sensation of the motion of atoms.
   - Count Rumford suggests that heat can be made in unlimited quantities by the use of mechanical energy.
   - 1840: J.P. Joule verifies Rumford's suggestion experimentally and proves that quantitative experiments equate heat to mechanical energy and heat is a form of energy, not a fluid.

2. If $\overset{1}{\cancel{m}}gh = \frac{7}{10}\overset{1}{\cancel{m}}v^2$,

   $v^2 = \frac{10}{7}gh$

   or $v^2\left[\frac{10}{7}g\right]h$

   - The line should pass through the origin.
   - The shape should equal $\frac{10}{7}g$.

$$\text{slope} = 12.2\ \text{m/s}^2 = \frac{10}{7}g$$

$$g = \frac{7}{10}\left(12.2\ \text{m/s}^2\right)$$

$$= 8.54\ \text{m/s}^2$$

$$\text{percent error} = \frac{9.81\ \text{m/s}^2 - 8.54\ \text{m/s}^2}{9.81\ \text{m/s}^2} \times 100$$

$$= 12.9\%$$

- The prediction is verified (except missing the origin).
- The design is adequate to answer the problem.
- The *x*-intercept implies that no motion occurs until some minimum height is reached. There is a retarding factor present due to friction between the marble and the ramp.

Section 2: Activity 1

1. The terms *kinetic* and *potential energy* are usually reserved for large-scale objects that can be seen. The term *thermal energy* is used when referring to the energy of molecules which are not visible.

2. Thermal energy can be transferred by conduction, convection, and radiation.

   When the warm molecules of the pop collide with the cool, slower moving molecules of the ice, energy is transferred to the ice by conduction.

   The pop in the glass will have convection currents set up as the warm pop rises to the top and the cool pop sinks to the bottom of the glass, creating circulation.

   As the glass sits on the beach, it absorbs thermal energy from the sun in the form of radiation. Even if the glass is put in the shade, the surrounding hot objects (sand, rocks, etc.) will reradiate their own thermal energy.

3. A lake filled with cool water has much more thermal energy than a can of warm pop because thermal energy refers to the **total** energy of an object's molecules. The lake has so many molecules that, despite the fact that the molecules have less kinetic energy on **average**, the sheer numbers make the total energy much larger.

   The can of pop has a higher temperature, which means that the **average** kinetic energy of the pop molecules is higher than the **average** kinetic energy of the lake molecules. The key to keeping these ideas straight is to link the word *total* with thermal energy and the word *average* with temperature.

4. The lowest temperature possible is absolute zero.

5. Since temperature is defined as the average kinetic energy of molecules, it makes sense that zero temperature would be associated with zero kinetic energy of molecules.

6. Heat is the flow or transfer of thermal energy from a high temperature area to an area of lower temperature. An object cannot possess a flow since this implies a process.

7. a. This is an open system because the exhaust products from burning the gasoline leave the car and enter the atmosphere.

   b. This is an open system because carbon dioxide, oxygen, water, and other nutrients enter and leave through the cell membrane.

c. This system is very nearly closed. Molecules can transfer through the apple's skin, but this mass is such a tiny part of the total that no appreciable amount of mass is exchanged.

8. a. The car is not an isolated system because the external force of air resistance acts on the car. To overcome this force, the engine must convert the chemical potential energy of the gasoline into the kinetic energy of the car. In the process, thermal energy and sound are created Thermal energy and sound leave the system and pass into the environment. Since this energy leaves the system, the system is not isolated.

b. The muscle cell is not an isolated system. The kinetic energy for contracting muscle fibres comes from the oxidation of ATP into ADP. This oxidation reaction releases thermal energy that is conducted away from the cell.

c. The falling apple is not an isolated system because the force of gravity is an external force that does work on the apple by converting potential energy to kinetic energy. However, the earth and the apple could together be considered a nearly isolated system because the force of gravity would be an internal force of the system.

9. a. This system converts the gravitational potential energy stored between the steel ball and the earth into the kinetic energy of the cart. If the thermal energy and sound energy that leave this system (due to frictional effects) are small, $E_p = E_k$ and $mgh = \tfrac{1}{2}mv^2$ could be used to describe this system.

b. This system converts the electrical energy from the wall outlet into thermal energy, which then flows as heat to the water. If very little of the thermal energy leaves the water in the cup, $E_{electric} = E_{thermal}$ and $P \bullet t = mc\Delta T$ could be used to describe this system.

c. This system converts elastic potential energy stored in the slingshot (when work is done pulling the rock back) to the kinetic energy of the released rock. Part of this kinetic energy will be converted to gravitational potential energy as the rock rises in the air. Finally, the energy of the rock is entirely kinetic as it falls to the target. If the thermal energy and sound energy that leave this system are small, the following equations would closely describe this system:

$$E_{elastic} = E_k = E_k + E_p = E_k$$

$$F \bullet d = \frac{1}{2}mv_1{}^2 = \frac{1}{2}mv_2{}^2 + mgh = \frac{1}{2}mv_3{}^2$$

Section 2: Activity 2

Investigation: Conservation of Energy on an Air Table

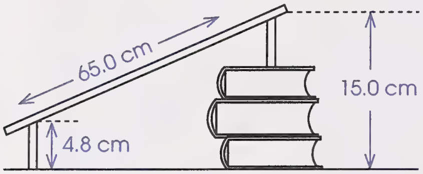
1. The closed, isolated system being studied includes the puck, the air table, and the earth. The thermal energy generated through frictional effects should be small enough that potential energy and kinetic energy should always total a constant value.

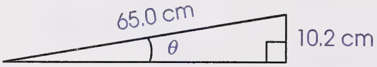
The following values are samples of the data that you should have written into the upper right corner of your newsprint paper. Your values may vary from those shown. Note that the sample values provided here are the values that will be used throughout the sample calculations for this investigation.

height difference: 10.2 cm
table length: 65.0 cm
mass of puck: 0.555 kg

2. The following calculation shows how the angle of incline was calculated with the sample data that was provided.

   The table setup looks like this.





$$\sin\theta = \frac{\text{opposite}}{\text{hypotenuse}}$$
$$= \frac{10.2\ \text{cm}}{65.0\ \text{cm}}$$
$$= 0.1569$$
$$\theta = 9.03°$$

3. Since the horizontal speed is a constant for projectile motion, the horizontal kinetic energy should also be a constant.

The following is a sample of Table 1 that you should have in your notebook. The values were collected from the sample air-table data provided on the tear-out page for this investigation. This is the data that would be collected from Part B of the procedure. If you used Part A of the procedure, your values may differ, but the trends in the data should be similar.

Table 1

Time (s)	Vertical Distance from Previous Dot (m)	Average Vertical Speed in Interval (m/s)	Length from Reference Level (m)	Height Above Reference Level (m)
0	–	–	0.035	0.0055
0.100	0.071	0.71	0.106	0.017
0.200	0.054	0.54	0.159	0.025
0.300	0.039	0.39	0.198	0.031
0.400	0.023	0.23	0.220	0.034
0.500	0.007	0.07	0.227	0.036
0.600	0.009	0.09	0.218	0.034
0.700	0.026	0.26	0.192	0.030
0.800	0.041	0.41	0.152	0.024
0.900	0.056	0.56	0.096	0.015
1.000	0.072	0.72	0.024	0.0038

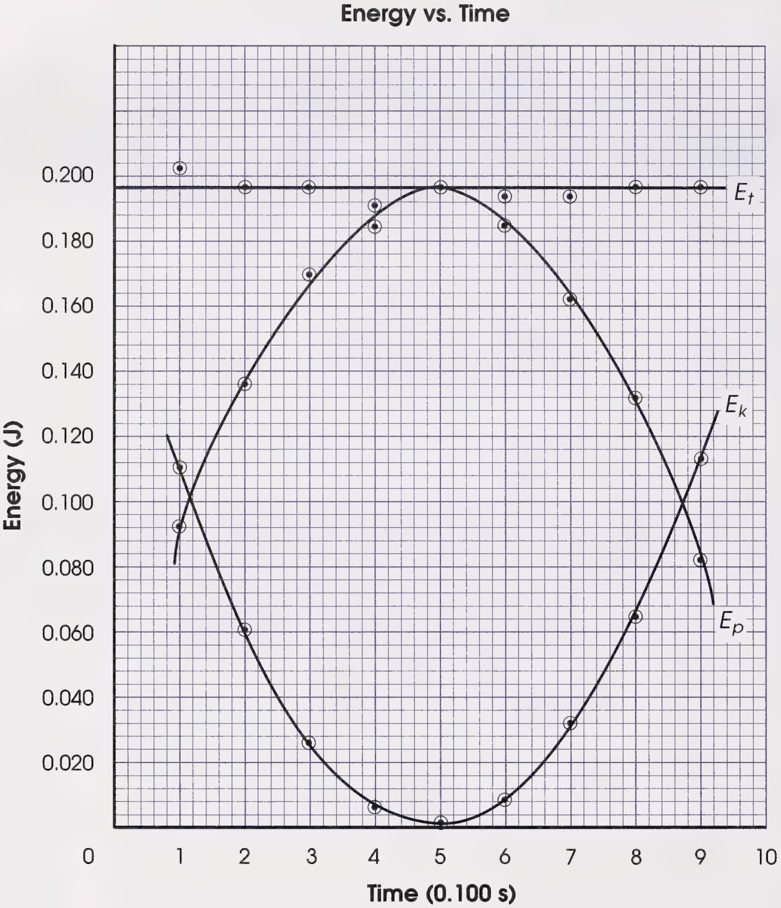
The following is a sample of Table 2 that you should have completed in your notebook. The values were collected from the sample air-table data provided on the tear-out page for this investigation. This is the data that would be collected from Part B of the procedure. If you used Part A of the procedure, your values may differ, but the trends in the data should be similar.

Table 2

Time (s)	Height Above Reference Level (m)	Instantaneous Speed (m/s)	Speed Squared (m^2/s^2)	Potential Energy (J)	Kinetic Energy (J)	Total Energy (J)
0	0.0055	–	–	–	–	–
0.100	0.017	0.625	0.391	0.093	0.108	0.201
0.200	0.025	0.465	0.216	0.136	0.060	0.196
0.300	0.031	0.310	0.096	0.169	0.027	0.196
0.400	0.034	0.150	0.023	0.185	0.006	0.191
* 0.500	0.036	0.000	0.000	0.196	0.000	0.196
0.600	0.034	0.175	0.031	0.185	0.009	0.194
0.700	0.030	0.335	0.112	0.163	0.031	0.194
0.800	0.024	0.485	0.235	0.131	0.065	0.196
0.900	0.015	0.640	0.410	0.082	0.114	0.196
1.000	0.0038	–	–	–	–	–

*Note that the speed at the top of the path is best estimated to be zero because the average speeds of the intervals before and after are in different directions and nearly identical.

4. The following graph is consistent with the values shown in Tables 1 and 2. This is the graph that reflects the sample air-table data provided on the tear-out page for this investigation. This graph also reflects the data collected from Part B of the procedure. If you used Part A of the procedure, your graph may differ, but the trends shown by the shapes of the lines should be similar.



5. Referring to the sample data presented in the previous graph, the prediction is verified to a high degree of accuracy.

6. The total energy remains constant. The kinetic energy decreases at the same rate that the potential energy increases. One does convert into the other.

7. The air table helps to reduce the amount of energy transferred to thermal energy through frictional effects. The air cushion that the puck rides on keeps friction to a minimum.

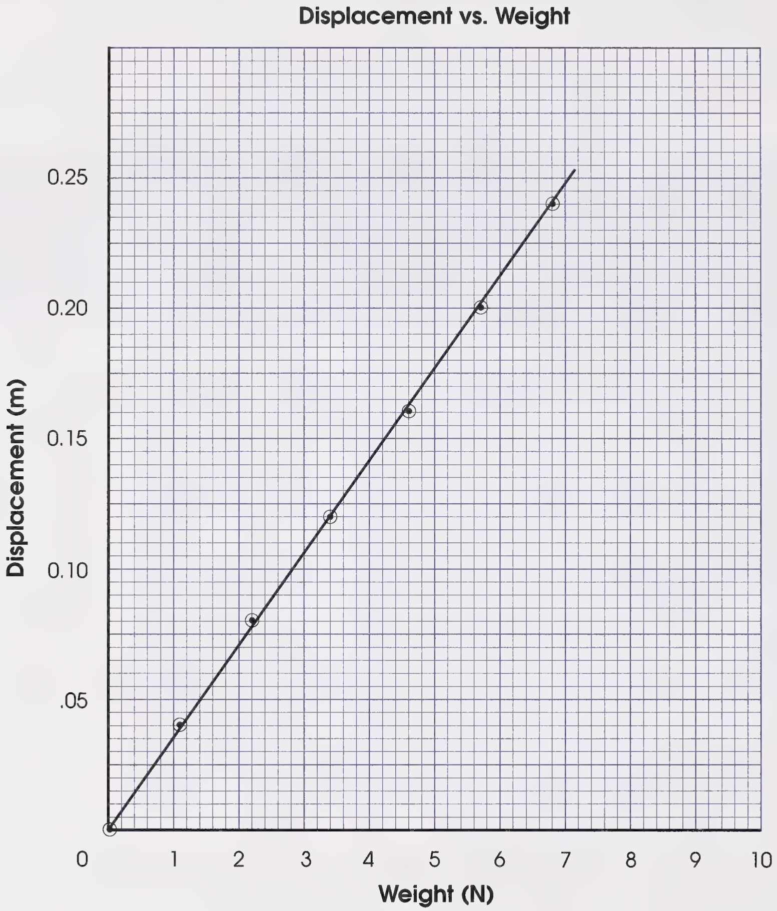
Section 2: Activity 3

Investigation: Properties of Mass on a Spring

The following data was collected using $\frac{1}{4}$-lb (113.5-g) blocks of margarine in a plastic bag. Your results may vary if you used different masses or a different spring. However, the basic trends in the data should be the same.

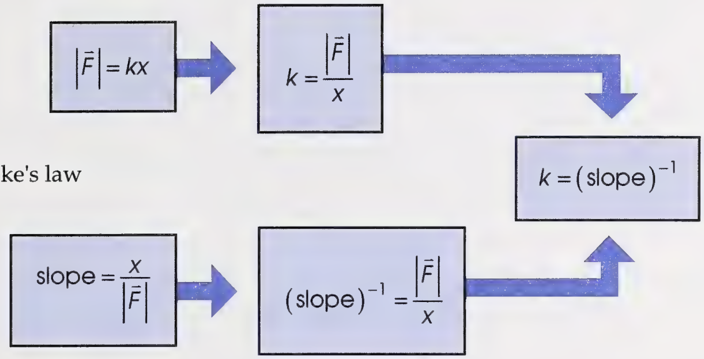
Mass on Spring (kg)	Weight on Spring (N)	Paper Clip Position (cm)	Displacement from Unloaded Position (m)	Time for Fifty Oscillations (s)	Period of Vibration (s)	Period Squared (s^2)
0	0	39.4	0	–	–	–
0.114	1.12	43.4	0.04	24.1	0.482	0.232
0.227	2.23	47.4	0.08	31.5	0.630	0.397
0.341	3.35	51.4	0.12	37.2	0.744	0.554
0.454	4.45	55.4	0.16	42.5	0.850	0.723
0.568	5.57	59.4	0.20	47.0	0.940	0.884
0.681	6.68	63.5	0.24	51.3	1.026	1.053

1. The following graph reflects the sample data presented on the data chart. If you used a different spring or different masses, the details of your graph will vary, but the trend in the data will be the same.



2. The following calculations are based upon the sample data in the data chart and the graph in question 1.

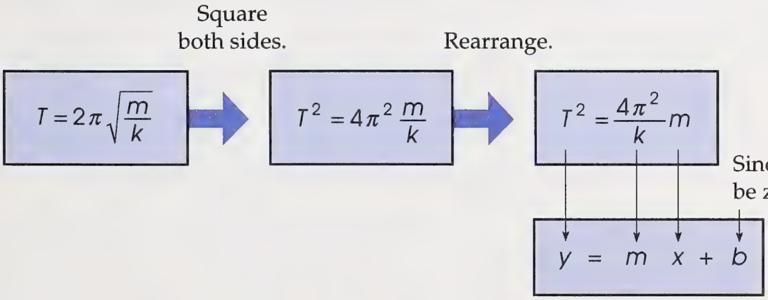
$$\begin{aligned}\text{slope} &= \frac{\text{rise}}{\text{run}}\\ &= \frac{(0.225\ \text{m} - 0\ \text{m})}{(6.40\,\text{N} - 0\ \text{N})}\\ &= 0.0352\ \text{m/N}\\ &= 0.035\ \text{m/N}\end{aligned}$$


$\left|\vec{F}\right| = kx$
$k = \frac{\left|\vec{F}\right|}{x}$
Hooke's law
$k = (\text{slope})^{-1}$
$\text{slope} = \frac{x}{\left|\vec{F}\right|}$
$(\text{slope})^{-1} = \frac{\left|\vec{F}\right|}{x}$

$$\begin{aligned}k &= (0.0352\ \text{m/N})^{-1}\\ &= 28.4\ \text{N/m}\\ &= 28\ \text{N/m}\end{aligned}$$

3. The graph helps to verify that the motion of the mass on the spring is simple harmonic motion. The graph shows that the restoring force is proportional to the displacement of the spring. Since the restoring force always acted in the opposite direction of the displacement, the vector nature of simple harmonic motion is also exemplified.

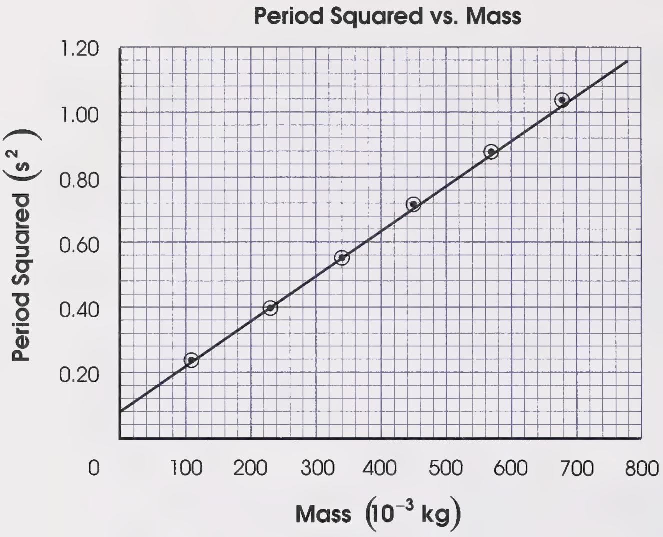
4.


Square both sides.
Rearrange.
$T = 2\pi\sqrt{\frac{m}{k}}$
$T^2 = 4\pi^2\frac{m}{k}$
$T^2 = \frac{4\pi^2}{k}m$
$y = m\ x + b$

Since there is no term left, *b* should be zero.

As the flow chart shows, a graph with T^2 on the *y*-axis and *m* on the *x*-axis should produce a straight-line graph with a slope of $\frac{4\pi^2}{k}$.

5. The following graph is based on the sample data presented earlier in the investigation. If you used different equipment, your graph may be slightly different, but the trend in the data should be the same.



6.
$$\begin{aligned}
\text{slope} &= \frac{\text{rise}}{\text{run}} \\
&= \frac{(1.05\ \text{s}^2 - 0.36\ \text{s}^2)}{(0.70\ \text{kg} - 0.20\ \text{kg})} \\
&= \frac{0.69\ \text{s}^2}{0.50\ \text{kg}} \\
&= 1.38\ \text{s}^2/\text{kg} \\
&= 1.4\ \text{s}^2/\text{kg}
\end{aligned}$$

7. The slope of this graph is equal to $\frac{4\pi^2}{k}$. Therefore, the value of k can be determined as follows:

$$\begin{aligned}
\text{slope} &= \frac{4\pi^2}{k} \\
k &= \frac{4\pi^2}{\text{slope}} \\
&= \frac{4\pi^2}{(1.38\ \text{s}^2/\text{kg})} \\
&= 28.6\ \text{kg}/\text{s}^2 \\
&= 29\ \text{kg}/\text{s}^2
\end{aligned}$$

Note that these units are equivalent to N/m.

$$\frac{1\ \text{N}}{\text{m}} = \frac{1\ \text{kg}\bullet\cancel{\text{m}}/\text{s}^2}{\cancel{\text{m}}} = \frac{1\ \text{kg}}{\text{s}^2}$$

This value for slope compares very well to the earlier value of 28.4 N/m. In terms of a percent error between these values, it is very low, as shown by the following calculation:

$$\begin{aligned}\frac{|28.4\ \text{N/m} - 28.6\ \text{N/m}|}{28.4\ \text{N/m}} \times 100\% &= 0.704\% \\ &= 0.70\%\end{aligned}$$

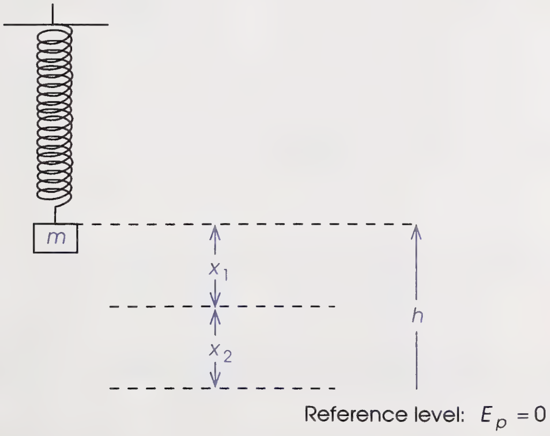
8. The mass on the spring satisfies both of the equations for simple harmonic motion: $\vec{F}_s = -k\vec{x}$ and $T = 2\pi\sqrt{\frac{m}{k}}$. This was demonstrated by the graphing of data that produced straight-line graphs consistent with each of these equations.

9. When the method given by the equation $\vec{F}_s = -k\vec{x}$ was used, errors could be attributed to accurately measuring the displacement and to inconsistencies in the standard masses. If the blocks of margarine were used, for example, the paper wrappers around each block and the mass of the plastic bag could have contributed to errors. Other errors could have been introduced by the mass of the spring itself, which was not accounted for in the calculations.

   The second method, using the equation $T = 2\pi\sqrt{\frac{m}{k}}$, would have had timing errors instead of displacement errors, as well as the same errors associated with mass measurements.

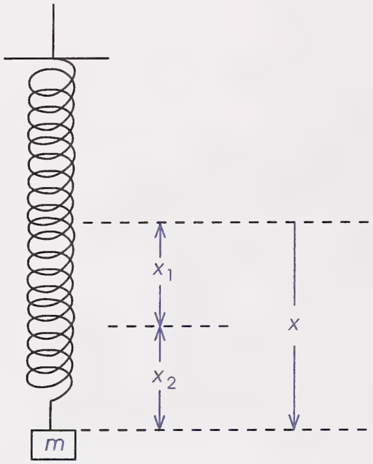
10. At Step 4 the spring would have kinetic energy because it is moving. It would also have gravitational potential energy because it is above the reference level and it would have spring potential energy because the coils are stretched below the unloaded position.

11. Gravitational potential energy could be calculated as follows:

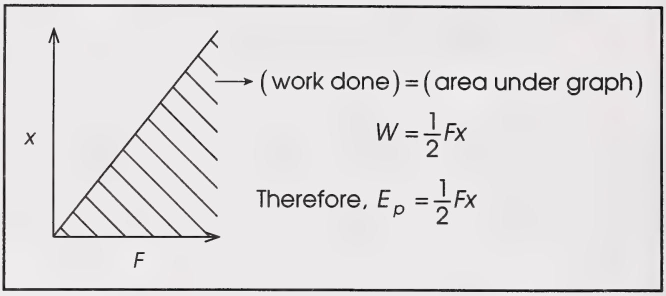


$$\begin{aligned}E_p &= \text{work done against gravity} \\ &= mgh \\ &= mg(x_1 + x_2)\end{aligned}$$

12. Spring potential energy could be calculated as follows:



E_p = work done to stretch spring



x
F
(work done) = (area under graph)
$W = \frac{1}{2}Fx$
Therefore, $E_p = \frac{1}{2}Fx$

$$\begin{aligned} E_p &= \frac{1}{2}Fx \\ &= \frac{1}{2}(kx)x \quad \text{– Substituting Hooke's law} \\ &= \frac{1}{2}kx^2 \end{aligned}$$

13.

$$\boxed{E_p = \frac{1}{2}kx^2}$$

Substitute units.

$$\boxed{\mathrm{J} = \frac{\mathrm{N}}{\mathrm{m}} \bullet \mathrm{m}^2}$$

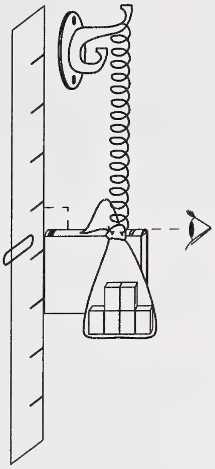
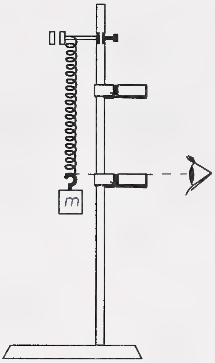
Simplify.

$$\boxed{\mathrm{J} = \mathrm{N} \bullet \mathrm{m}}$$

14. The procedure should include many of the diagrams and suggestions of the previous investigation. The steps in this procedure should closely match Steps 1 through 5 outlined in the introduction to this investigation.

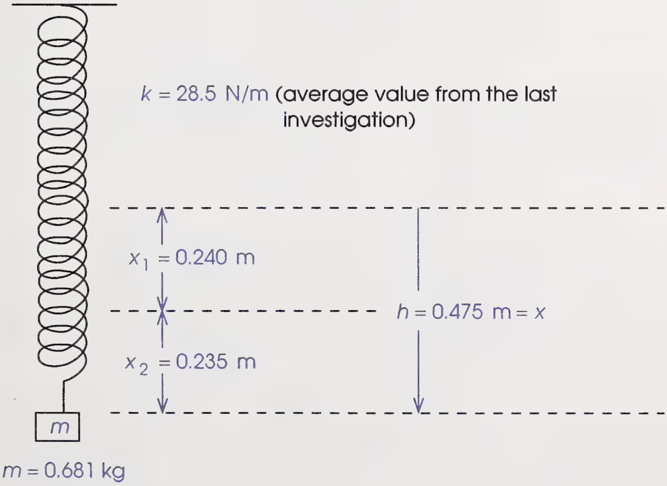
The crucial error-reducing techniques should focus on carefully measuring the displacements. Any efforts made at reducing errors here will make a big difference when it comes to the calculations.

Most errors with measuring displacement occur because it is difficult to keep the eye at the same angle to the spring and it is challenging to determine the lowest position. The following diagrams illustrate some of the techniques for reducing the errors.

Using the magarine blocks as standard masses.	Using the masses and ringstand from a school science lab
 Look along a book held tight to the wall while a friend raises and releases the masses.	 Look along clothespins attached to the ring stand while a friend raises and releases the masses.

The other way to reduce these errors is to do many trials with the same mass being released from the same point to find the best location for the lowest position.

15. The following results were obtained with the same spring and blocks of margarine used in the last investigation. If you used different equipment, your answers will vary, but the energy values should still be close to each other.


$k = 28.5$ N/m (average value from the last investigation)
$x_1 = 0.240$ m
$x_2 = 0.235$ m
$h = 0.475 \text{ m} = x$
m
$m = 0.681$ kg

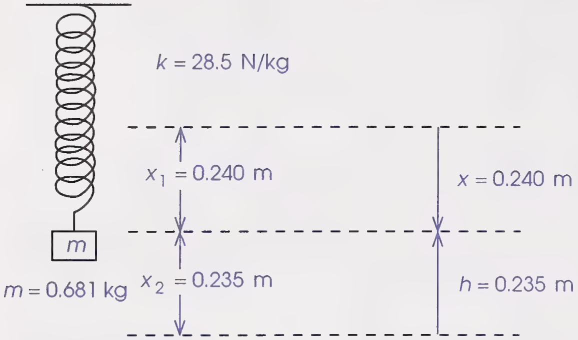
$$\begin{aligned} E_p &= \text{work done against gravity} \\ &= mgh \\ &= (0.681 \text{ kg})(9.81 \text{ m/s}^2)(0.475 \text{ m}) \\ &= 3.17 \text{ J} \end{aligned}$$

$$\begin{aligned} E_p &= \text{work done against spring} \\ &= \frac{1}{2}kx^2 \\ &= \frac{1}{2}(28.5 \text{ N/m})(0.475 \text{ m})^2 \\ &= 3.22 \text{ J} \end{aligned}$$

16. Based on the previous calculations, the energy does appear to be conserved. The percent error would be very small, as shown in the following calculations:

$$\frac{|3.17\ \text{J} - 3.22\ \text{J}|}{3.17\ \text{J}} \times 100\% = 1.58\%$$

17. The following calculation is consistent with the data presented for the previous two questions.



$$\begin{aligned} E_p &= mgh \\ &= (0.681\ \text{kg})(9.81\ \text{m/s}^2)(0.235\ \text{m}) \\ &= 1.57\ \text{J} \end{aligned}$$

$$\begin{aligned} E_p &= \frac{1}{2}kx^2 \\ &= \frac{1}{2}(28.5\ \text{N/kg})(0.240\ \text{m})^2 \\ &= 0.821\ \text{J} \end{aligned}$$

If energy is assumed to be conserved, the total energy should be a constant value. Using the data from the previous two questions, the total energy could be considered to be the average of 3.17 J and 3.22 J, which is 3.20 J. If these things are true, the kinetic energy could be calculated as follows:

$$\begin{aligned} \text{total energy at rest postion} &= \left(E_p\right)_{gravity} + \left(E_p\right)_{spring} + E_k \\ 3.20\ \text{J} &= 1.57\ \text{J} + 0.821\ \text{J} + E_k \\ E_k &= 0.809\ \text{J} \\ &= 0.81\ \text{J} \end{aligned}$$

18. The crucial measurement that would verify the previous calculation would be the speed of the mass as it passed through the rest position. This would allow the direct calculation of kinetic energy using $E_k = \frac{1}{2}mv^2$.

The difficulty with this measurement is that the motion is accelerated in the region immediately before the rest position and decelerated in the region immediately after the rest position. Since this is not a standard uniform motion situation, you would probably need to use special high-speed photographic equipment or something like a police radar gun. Even then, because the speed occurs at an instant, this would still only approximate the true speed because instantaneous speeds are impossible to measure.

19. The law of conservation of energy is so important to physics because it allows very complex problems to be analysed using a direct and concise technique and it has been shown to apply to any closed, isolated system, no matter what particular types of energy are involved.

Section 2: Activity 4

1. If the second hill of the roller coaster was higher than the first, there would not be enough gravitational potential energy stored to reach the top of the higher hill.

2. Work is done to lift the roller coaster to the top of the first hill. This work increases the gravitational potential energy of the roller coaster to a maximum value at the top of the first hill. Once the roller coaster moves down the other side of the first hill, its gravitational potential energy is converted partly to kinetic energy and partly to thermal energy. The thermal energy is passed to the cars, the track, and the air around the ride. This energy is unavailable to the roller coaster by the time it reaches the second hill, so the roller coaster will reach the top of the second hill with less energy than it had at the top of the first hill. For these reasons, the second hill must be lower.

3. The first step is crucial because the law of conservation of energy applies only to systems that are closed and isolated. If this is not true, there's no point in continuing with the solution.

4. a. The sum of the heat losses equals the sum of the heat gains. You may remember this from Science 10.

   b. The mass before equals the mass after. This is the basis of the law of conservation of mass that you may have used in chemistry courses.

   c. The sum of the wins equals the sum of the losses. This might describe a sports team having a mediocre season.

5. Textbook question 27:

$h = 4.50\ \text{m}$
$v = 0\ \text{m/s}$
$v' = ?$

$$\sum E_{before} = \sum E_{after}$$

$$E_p + E_k = E_p{}' + E_k{}'$$

$$mgh + \frac{1}{2}mv^2 = mgh' + \frac{1}{2}mv'^2$$

$$\overset{1}{\cancel{m}}gh + 0 = 0 + \frac{1}{2}\overset{1}{\cancel{m}}v'^2$$

$$v' = \sqrt{2gh}$$

$$= \sqrt{2\left(9.81\ \text{m/s}^2\right)\left(4.50\ \text{m}\right)}$$

$$= 9.40\ \text{m/s}$$

Textbook question 22. a.:

$m = 0.30\,\text{kg}$
$F = 201\ \text{N}$
$d = 1.3\ \text{m}$
$v' = ?$

$$\begin{aligned}
\sum E_{before} &= \sum E_{after}\\
E_p + E_k &= E_p{}' + E_k{}'\\
Fd + 0 &= 0 + \frac{1}{2}mv'^2\\
v' &= \sqrt{\frac{2Fd}{m}}\\
&= \sqrt{\frac{2(201\ \text{N})(1.3\ \text{m})}{0.30\ \text{kg}}}\\
&= 41.7\ \text{m/s}\\
&= 42\ \text{m/s}
\end{aligned}$$

Textbook question 22. b.:

$$\begin{aligned}
\sum E_{before} &= \sum E_{after}\\
E_k + E_p &= E_k{}' + E_p{}'\\
\frac{1}{2}mv^2 + mgh &= \frac{1}{2}mv'^2 + mgh'\\
\frac{1}{2}\overset{1}{\cancel{m}}v^2 + 0 &= 0 + \overset{1}{\cancel{m}}gh'\\
h' &= \frac{v^2}{2g}\\
&= \frac{(41.7\ \text{m/s})^2}{2(9.81\ \text{m/s}^2)}\\
&= 89\ \text{m}
\end{aligned}$$

If you can equate the work done by the bow to potential energy, you can do question 22.b. without doing question 22.a. first.

$$\begin{aligned}
\sum E_{before} &= \sum E_{after}\\
E_p + E_k &= E_p{}' + E_k{}'\\
W + \frac{1}{2}mv^2 &= \frac{1}{2}mv^2 + mgh\\
Fd + 0 &= 0 + mgh\\
Fd &= mgh\\
h &= \frac{Fd}{mg}\\
&= \frac{(201\ \text{N})(1.3\ \text{m})}{(0.30\ \text{kg})(9.81\ \text{m/s}^2)}\\
&= 89\ \text{m}
\end{aligned}$$

Textbook question 25:

$m_{ball} = 10.0\ \text{g} = 0.0100\ \text{kg}$
$h = 2.0\ \text{m}$
$v' = 7.5\ \text{m/s}$
$v = ?$

Here you are solving for speed in a place where neither E_p nor E_k is zero. This energy conservation method is particularly good in these cases.

$$\begin{aligned}
\sum E_{before} &= \sum E_{after}\\
E_p + E_k &= E_p{}' + E_k{}'\\
mgh + \frac{1}{2}mv^2 &= mgh' + \frac{1}{2}mv'^2\\
\overset{1}{\cancel{m}}gh + \frac{1}{2}\overset{1}{\cancel{m}}v^2 &= 0 + \frac{1}{2}\overset{1}{\cancel{m}}v'^2\\
v &= \sqrt{v'^2 - 2gh}\\
&= \sqrt{(7.5\ \text{m/s})^2 - 2(9.81\ \text{m/s}^2)(2.0\ \text{m})}\\
&= 4.1\ \text{m/s}
\end{aligned}$$

6. $h = 0.130 \text{ m}$

$v = 0 \text{ m/s}$

$v' = ?$

The pendulum drops 13.0 cm and picks up kinetic energy.

$$\begin{aligned}
\sum E_{before} &= \sum E_{after} \\
E_p + E_k &= E_p{}' + E_k{}' \\
mgh + \frac{1}{2}mv^2 &= mgh' + \frac{1}{2}mv'^2 \\
\overset{1}{\cancel{m}}gh + 0 &= 0 + \frac{1}{2}\overset{1}{\cancel{m}}v'^2 \\
v' &= \sqrt{2gh} \\
&= \sqrt{2\left(9.81 \text{ m/s}^2\right)(0.130 \text{ m})} \\
&= 1.60 \text{ m/s}
\end{aligned}$$

7. $m = 150 \text{ g} = 0.150 \text{ kg}$

$k = 11.0 \text{ N/m}$

$x = 0.500 \text{ m}$

$v' = ?$

$$\begin{aligned}
\sum E_{before} &= \sum E_{after} \\
E_p + E_k &= E_p{}' + E_k{}' \\
\frac{1}{2}kx^2 + \frac{1}{2}mv^2 &= \frac{1}{2}kx'^2 + \frac{1}{2}mv'^2 \\
\cancel{\frac{1}{2}}kx^2 + 0 &= 0 + \cancel{\frac{1}{2}}mv'^2 \\
v' &= \sqrt{\frac{kx^2}{m}} \\
&= \sqrt{\frac{(11.0 \text{ N/m})(0.500 \text{ m})^2}{0.150 \text{ kg}}} \\
&= 4.28 \text{ m/s}
\end{aligned}$$

8. $x' = 30.0 \text{ cm} = 0.300 \text{ m}$

$m = 150 \text{ g} = 0.150 \text{ kg}$

$k = 11.0 \text{ N/m}$

$x = 50.0 \text{ cm} = 0.500 \text{ m}$

$v' = ?$

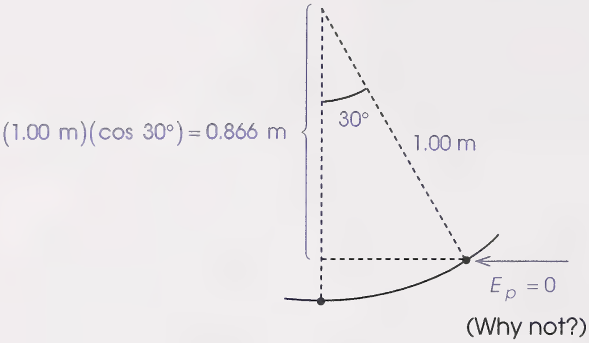
$$\begin{aligned}
\sum E_{before} &= \sum E_{after} \\
E_p + E_k &= E_p{}' + E_k{}' \\
\frac{1}{2}kx^2 + \frac{1}{2}mv^2 &= \frac{1}{2}kx'^2 + \frac{1}{2}mv'^2 \\
\cancel{\frac{1}{2}}kx^2 + 0 &= \cancel{\frac{1}{2}}kx'^2 + \cancel{\frac{1}{2}}mv'^2 \\
v' &= \sqrt{\frac{kx^2 - kx'^2}{m}} \\
&= \sqrt{\frac{(11.0 \text{ N/m})(0.500 \text{ m})^2 - (11.0 \text{ N/m})(0.300 \text{ m})^2}{0.150 \text{ kg}}} \\
&= 3.43 \text{ m/s}
\end{aligned}$$

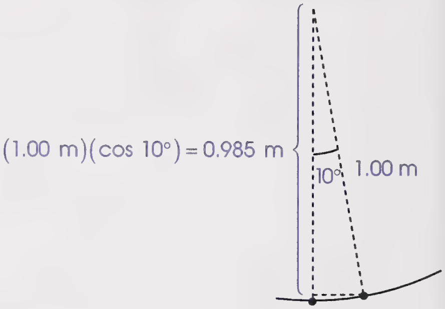
9. $\ell = 1.00\ \text{m}$

$\theta_1 = 30.0°$

$\theta_2 = 10.0°$

First draw a diagram! Use trigonometry to get vertical distances.





$$
\begin{aligned}
h &= (0.866\ \text{m}) - (0.985\ \text{m}) \\
&= -0.119\ \text{m}
\end{aligned}
$$

The bob has fallen 0.119 m.

$$
\begin{aligned}
\sum E_{before} &= \sum E_{after} \\
E_p + E_k &= E_p{}' + E_k{}' \\
0 + 0 &= \overset{1}{\cancel{m}}gh' + \frac{1}{2}\overset{1}{\cancel{m}}v'^2 \\
v' &= \sqrt{-2gh'} \\
&= \sqrt{-2\left(9.81\ \text{m/s}^2\right)\left(-0.119\ \text{m}\right)} \\
&= 1.53\ \text{m/s}
\end{aligned}
$$

$E_p = 0$ is arbitrary. It was used at the high point here. Any other place would give the same answer.

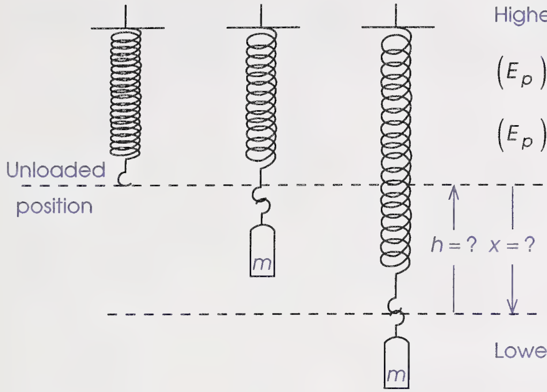
10. a. $m = 0.655\ \text{kg}$

$T = 0.827\ \text{s}$

$k = ?$

$$
\begin{aligned}
T &= 2\pi\sqrt{\frac{m}{k}} \\
T^2 &= 4\pi^2\left(\frac{m}{k}\right) \\
k &= \frac{4\pi^2 m}{T^2} \\
&= \frac{4\pi^2\left(0.655\ \text{kg}\right)}{\left(0.827\ \text{s}\right)^2} \\
&= 37.8\ \text{N/m}
\end{aligned}
$$

b.



Highest position of vibration:

$$(E_p)_{spring} = 0$$

$$(E_p)_{gravity} = mgh$$
$$= mgx$$

Lowest postion of vibration:

$$(E_p)'_{spring} = \frac{1}{2}kx^2$$

$$(E_p)'_{gravity} = 0$$

$$\sum E_{before} = \sum E_{after}$$

$$(E_p)_{spring} + (E_p)_{gravity} = (E_p)_{spring}{}' + (E_p)_{gravity}{}'$$

$$0 + mgh = \frac{1}{2}kx^2 + 0$$

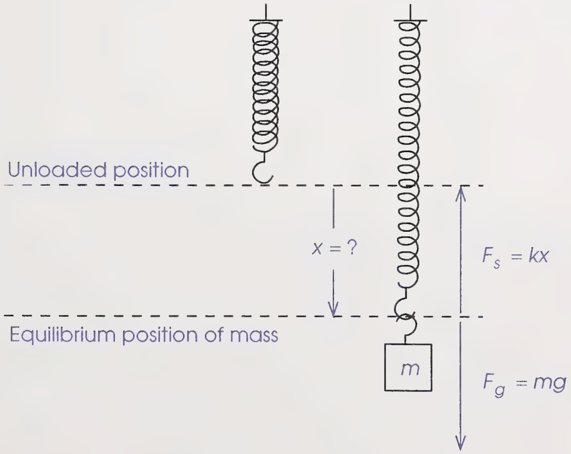
$$mgx = \frac{1}{2}kx^2$$

$$x = \frac{2mg}{k}$$

$$= \frac{2(0.655\ \text{kg})(9.81\ \text{m/s}^2)}{37.8\ \text{N/m}}$$

$$= 0.340\ \text{m}$$

c.



$$F_s = F_g$$

$$kx = mg$$

The forces are in equilibrium.

$$x = \frac{mg}{k}$$

$$= \frac{(0.655\ \text{kg})(9.81\ \text{m/s}^2)}{37.8\ \text{N/m}}$$

$$= 0.170\ \text{m}$$

d. Since the vibrating mass on the spring undergoes simple harmonic motion, it vibrates around the equilibrium position for the mass and spring. In other words, the rest position is in the centre of the highest and lowest points of vibration. Since these points are separated by 0.340 m, the rest position should be half way, or 0.170 m, below the highest point.

11. $m = 0.185\ \text{kg}$

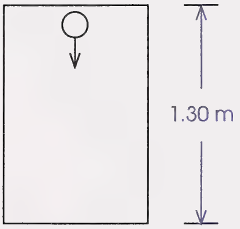
$d = 35.6\ \text{cm} = 0.356\ \text{m}$

$x = 28.8\ \text{cm} = 0.288\ \text{m}$

$k = ?$

$$\begin{aligned}
\sum E_{before} &= \sum E_{after} \\
(E_p)_{spring} + (E_p)_{gravity} &= (E_p)_{spring}' + (E_p)_{gravity}' \\
0 + mgh &= \frac{1}{2}kx^2 + 0 \\
mgh &= \frac{1}{2}kx^2 \\
mg(d+x) &= \frac{1}{2}kx^2 \\
k &= \frac{2mg(d+x)}{x^2} \\
&= \frac{2(0.185\ \text{kg})(9.81\ \text{m/s}^2)(0.356\ \text{m} + 0.288\ \text{m})}{(0.288\ \text{m})^2} \\
&= 28.2\ \text{N/m}
\end{aligned}$$

12.



$v = 8.8\ \text{m/s}$

$h = 1.30\ \text{m}$ (assuming $E_p = 0$ is at the bottom of the window)

$v' = ?$

$$\begin{aligned}
\sum E_{before} &= \sum E_{after} \\
E_p + E_k &= E_p' + E_k' \\
\overset{1}{\cancel{m}}gh + \frac{1}{2}\overset{1}{\cancel{m}}v^2 &= 0 + \frac{1}{2}\overset{1}{\cancel{m}}v'^2 \\
v' &= \sqrt{2\left(gh + \frac{1}{2}v^2\right)} \\
&= \sqrt{2\left[(9.81\ \text{m/s}^2)(1.30\ \text{m}) + \frac{1}{2}(8.8\ \text{m/s})^2\right]} \\
&= 10\ \text{m/s}
\end{aligned}$$

13. The work done against friction creates thermal energy.

14. The creation of thermal energy could be verified by measuring the change in temperature and the mass of the marble and the floor. These measurements would be very challenging.

15. Textbook question 26:

$m = 28\text{ kg}$
$h = 4.8\text{ m}$
$v' = 3.2\text{ m/s}$
$v = 0\text{ m/s}$
$W' = ?$

$$\begin{aligned}\sum E_{before} &= \sum E_{after}\\ mgh + \frac{1}{2}mv^2 &= mgh' + \frac{1}{2}mv'^2 + W'\\ mgh + 0 &= 0 + \frac{1}{2}mv'^2 + W'\\ W' &= mgh - \frac{1}{2}mv'^2\\ &= (28\text{ kg})(9.81\text{ m/s}^2)(4.8\text{ m}) - \frac{1}{2}(28\text{ kg})(3.2\text{ m/s})^2\\ &= 1.2\times10^3\text{ J}\end{aligned}$$

16. Textbook question 4:

$m = 82.0\text{ kg}$
$v = 4.2\text{ m/s}$
$F_f = 140\text{ N}$

Since the friction term removes energy, you don't need the negative sign.

$$\begin{aligned}\sum E_{before} &= \sum E_{after}\\ E_p + E_k &= E_p{}' + E_k{}' + W'\\ mgh + \frac{1}{2}mv^2 &= mgh' + \frac{1}{2}mv'^2 + W'\\ 0 + \frac{1}{2}mv^2 &= 0 + 0 + F_f d\\ d &= \frac{\frac{1}{2}mv^2}{F_f}\\ &= \frac{\frac{1}{2}(82.0\text{ kg})(4.2\text{ m/s})^2}{140\text{ N}}\\ &= 5.2\text{ m}\end{aligned}$$

17. $v = 0\text{ m/s}$
$v' = 0\text{ m/s}$
$h = 0.95\text{ m}$
$h' = 0.38\text{ m}$
$d = 1.36\text{ m}$
$m = 0.0100\text{ kg}$

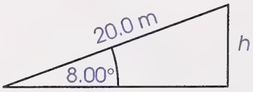
$$\begin{aligned}\sum E_{before} &= \sum E_{after}\\ E_p + E_k &= E_p{}' + E_k{}' + W'\\ mgh + \frac{1}{2}mv^2 &= mgh' + \frac{1}{2}mv'^2 + F_f d\\ mgh + 0 &= mgh' + 0 + F_f d\\ F_f &= \frac{mgh - mgh'}{d}\\ &= \frac{(0.0100\text{ kg})(9.81\text{ m/s}^2)(0.95\text{ m}) - (0.0100\text{ kg})(9.81\text{ m/s}^2)(0.38\text{ m})}{1.36\text{ m}}\\ &= 0.041\text{ N}\end{aligned}$$

18. $m = 1400\ \text{kg}$

$d = 20.0\ \text{m}$

$\theta = 8.00°$

$F_f = 200\ \text{N}$



$$h = 20.0(\sin 8.00°)$$
$$= 2.78\ \text{m}$$

$$\sum E_{before} = \sum E_{after}$$
$$E_p + E_k = E_p{'} + E_k{'} + W'$$
$$mgh + 0 = 0 + \frac{1}{2}mv'^2 + F_f d$$
$$v' = \sqrt{\frac{2(mgh - F_f d)}{m}}$$
$$= \sqrt{\frac{2\left[(1400\ \text{kg})(9.81\ \text{m/s}^2)(2.78\ \text{m}) - (200\ \text{N})(20.0\ \text{m})\right]}{1400\ \text{kg}}}$$
$$= 6.99\ \text{m/s}$$

19. $m = 900\ \text{kg}$

$v' = 0\ \text{m/s}$

$v = 20.0\ \text{m/s}$

$d = 60.0\ \text{m}$

$F_f = ?$

$$\sum E_{before} = \sum E_{after}$$
$$E_p + E_k = E_p{'} + E_k{'} + W'$$
$$0 + \frac{1}{2}mv^2 = 0 + 0 + F_f d$$
$$F_f = \frac{\frac{1}{2}mv^2}{d}$$
$$= \frac{\frac{1}{2}(900\ \text{kg})(20.0\ \text{m/s})^2}{60.0\ \text{m}}$$
$$= 3.00 \times 10^3\ \text{N}$$

20. a. $m = 5.0 \times 10^3\ \text{kg/s}$

$h = 200\ \text{m}$

$P = 6.9 \times 10^6\ \text{W} = 6.9 \times 10^6\ \text{J/s}$

$$E_p = mgh$$
$$= (5.0 \times 10^3\ \text{kg})(9.81\ \text{m/s}^2)(200\ \text{m})$$
$$= 9.8 \times 10^6\ \text{J}$$

b. The useful energy produced each second can be determined from the power output of 6.9×10^6 W or 6.9×10^6 J/s.

c. $\sum E_{before} = \sum E_{after}$ ← In one second

$E_p + E_k = E_p{'} + E_k{'} + W'$ ← The $E_k{'}$ is the energy left to make the electricity.

$$mgh + 0 = 0 + (6.9 \times 10^6\ \text{J}) + W'$$
$$W' = mgh - (6.9 \times 10^6\ \text{J})$$
$$= (5.0 \times 10^3\ \text{kg})(9.81\ \text{m/s}^2)(200\ \text{m}) - (6.9 \times 10^6\ \text{J})$$
$$= 2.9 \times 10^6\ \text{J in one second}$$

$$\left[\frac{2.9\times10^{6}\ \text{J}}{1\ \text{s}}\right]\times\left[\frac{60\ \text{s}}{1\ \text{min}}\right]\times\left[\frac{60\ \text{min}}{1\ \text{h}}\right]\times\left[\frac{24\ \text{h}}{1\ \text{d}}\right]=2.5\times10^{11}\ \text{J/d}$$

d. $$\frac{\text{useful energy}}{\text{input energy}}\times100\%=\frac{6.9\times10^{6}\ \text{J}}{9.8\times10^{6}\ \text{J}}\times100\%=70\%$$

21. $v=1.00\times10^{3}\ \text{m/s}$

$v'=7.5\times10^{2}\ \text{m/s}$

$m=7.0\times10^{3}\ \text{kg}$

$$\begin{aligned}\sum E_{before}&=\sum E_{after}\\ E_p+E_k&=E_p'+E_k'+W'\\ 0+\frac{1}{2}mv^2&=0+\frac{1}{2}mv'^2+W'\\ W'&=\frac{1}{2}mv^2-\frac{1}{2}mv'^2\\ &=\frac{1}{2}m\left(v^2-v'^2\right)\\ &=\frac{1}{2}\left(7.0\times10^{3}\ \text{kg}\right)\left[\left(1.00\times10^{3}\ \text{m/s}\right)^2-\left(7.5\times10^{2}\ \text{m/s}\right)^2\right]\\ &=1.5\times10^{9}\ \text{J or }1.5\ \text{GJ}\end{aligned}$$

Section 2: Follow-up Activities

Extra Help

1. a. The firecracker is about to convert chemical potential energy to thermal energy, sound energy, and light energy.

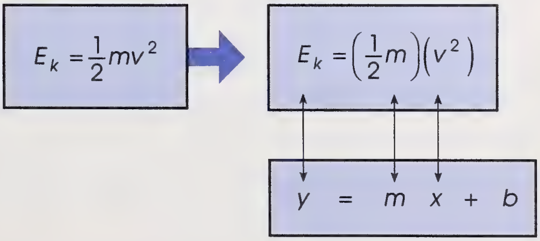
   The toy car is about to convert gravitational potential energy into kinetic energy and thermal energy.

   The candle is about to convert chemical potential energy into thermal energy and light energy.

   b. Although this system is closed, it is not isolated. Both light energy and thermal energy are able to leave the system through the glass.

2. The thermal energy from the soup flows as heat to the outside parts of the insulated bottle and then to the environment.

3. a. Rearrange.



b. The slope of this graph should be equal to one half of the mass.

4. $m = 20.0\ \text{kg}$

$d = 14.0\ \text{m}$

$F_f = 2.0\ \text{N}$

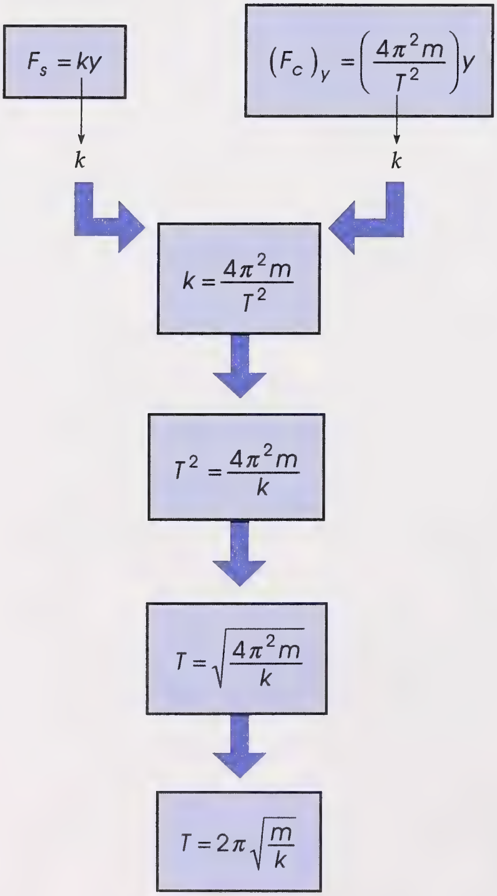
$v = ?$

$v' = 0\ \text{m/s}$

$$\begin{aligned}
\sum E_{before} &= \sum E_{after} \\
E_p + E_k &= E_p{}' + E_k{}' + W' \\
0 + \frac{1}{2}mv^2 &= 0 + 0 + F_f d \\
v &= \sqrt{\frac{2(F_f d)}{m}} \\
&= \sqrt{\frac{2(2.0\ \text{N})(14.0\ \text{m})}{20.0\ \text{kg}}} \\
&= 1.7\ \text{m/s}
\end{aligned}$$

Enrichment

1.


$F_s = ky$
$(F_c)_y = \left(\frac{4\pi^2 m}{T^2}\right)y$
k
k
$k = \frac{4\pi^2 m}{T^2}$
$T^2 = \frac{4\pi^2 m}{k}$
$T = \sqrt{\frac{4\pi^2 m}{k}}$
$T = 2\pi\sqrt{\frac{m}{k}}$

2. Find out how much energy is left over at A, B, C, and D and whether this is enough to reach the top of the next hill. The algebraic solution is always as shown.

$$\sum E_{before} = \sum E_{after}$$

$$E_p + E_k = E_p{}' + E_k{}' + W'$$

At A:

$$mgh + 0 = 0 + \frac{1}{2}mv'^2 + Fd$$

$$\begin{aligned} v' &= \sqrt{\frac{2(mgh - Fd)}{m}} \\ &= \sqrt{\frac{2\left[(800\text{ kg})(9.81\text{ m/s}^2)(12.0\text{ m}) - (1300\text{ N})(14.0\text{ m})\right]}{800\text{ kg}}} \\ &= 13.78\text{ m/s} \\ &= 13.8\text{ m/s} \end{aligned}$$

To top of hill:

$$0 + \frac{1}{2}mv^2 = mgh' + \frac{1}{2}mv'^2 + Fd$$

$$\begin{aligned} v' &= \sqrt{\frac{2\left(\frac{1}{2}mv^2 - mgh' - Fd\right)}{m}} \\ &= \sqrt{\frac{2\left[\frac{1}{2}(800\text{ kg})(13.78\text{ m/s})^2 - (800\text{ kg})(9.81\text{ m/s}^2)(8.0\text{ m}) - (1300\text{ N})(10.0\text{ m})\right]}{800\text{ kg}}} \\ &= 0.65\text{ m/s} \text{ – It made it.} \end{aligned}$$

To B:

$$mgh + \frac{1}{2}mv^2 = 0 + \frac{1}{2}mv'^2 + Fd$$

$$\begin{aligned} v' &= \sqrt{\frac{2\left(mgh + \frac{1}{2}mv^2 - Fd\right)}{m}} \\ &= \sqrt{\frac{2\left[(800\text{ kg})(9.81\text{ m/s}^2)(8.0\text{ m}) + \frac{1}{2}(800\text{ kg})(0.65\text{ m/s})^2 - (1300\text{ N})(10.0\text{ m})\right]}{800\text{ kg}}} \\ &= 11.2\text{ m/s} \text{ – It made it again.} \end{aligned}$$

To top of next hill:

$$0+\frac{1}{2}mv^2=mgh'+\frac{1}{2}mv'^2+Fd$$

$$v'=\sqrt{\frac{2\left(\frac{1}{2}mv^2-mgh'-Fd\right)}{m}}$$

$$=\sqrt{\frac{2\left[\frac{1}{2}(800\text{ kg})(11.2\text{ m/s})^2-(800\text{ kg})\left(9.81\text{ m/s}^2\right)(6.0\text{ m})-(1300\text{ N})(7.0\text{ m})\right]}{800\text{ kg}}}$$

$$=\sqrt{-15.03\text{ m}^2/\text{s}^2}$$

This is an undefined value for speed. The car can't make it up the hill. It ends at B.

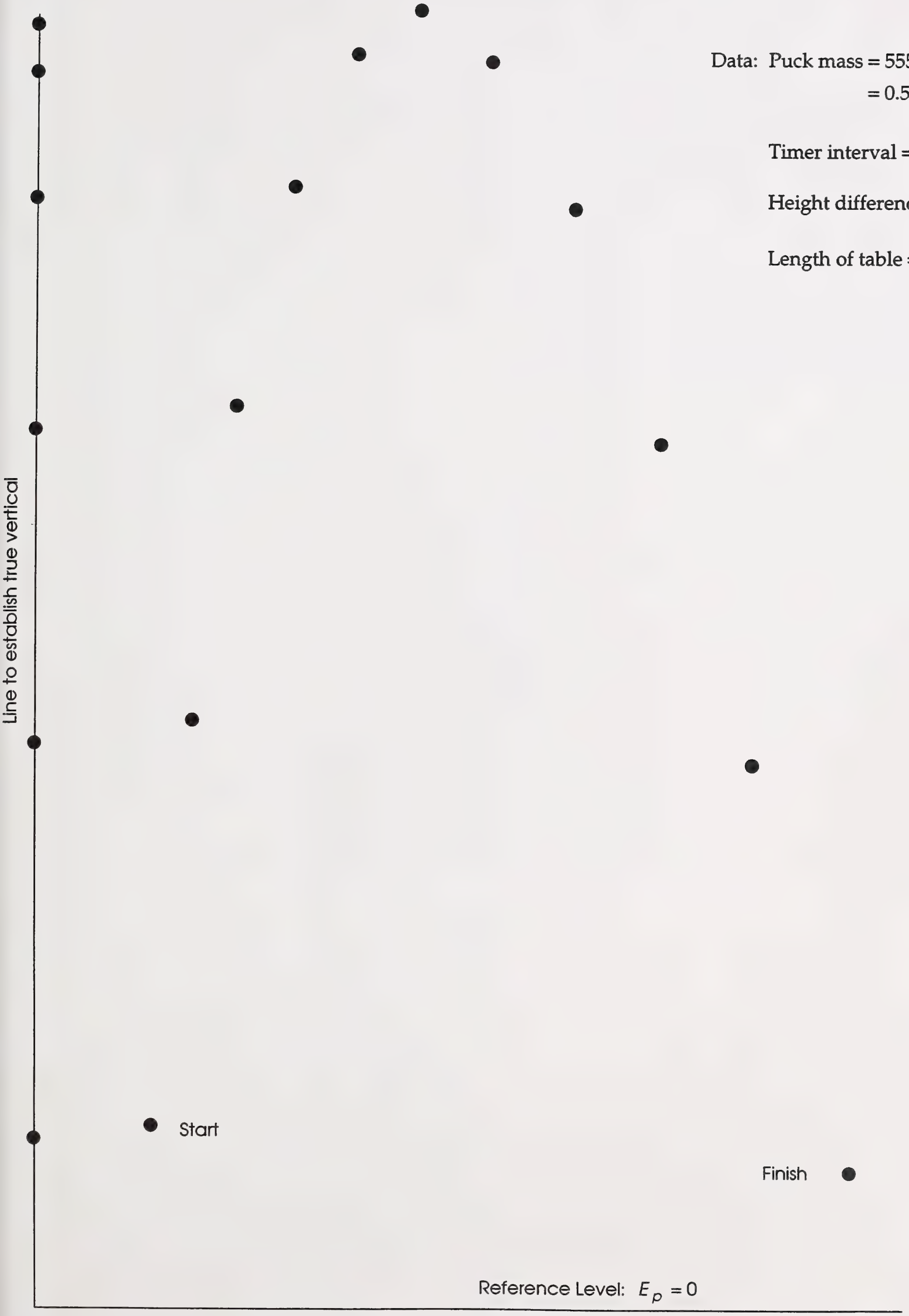
Investigation: Conservation of Energy on an Air Table

Data: Puck mass = 555 g
= 0.555 kg

Timer interval = 0.100 s

Height difference = 10.2 cm

Length of table = 65.0 cm



NOTES

NOTES

NOTES

NOTES

NOTES

NOTES

National Library of Canada
Bibliothèque nationale du Canada
3 3286 50429 1069

Physics 30

Student Module Booklet

Module 1

L.R.D.C.
Producer

1994